1-1-1979

Global radiation in West Virginia.

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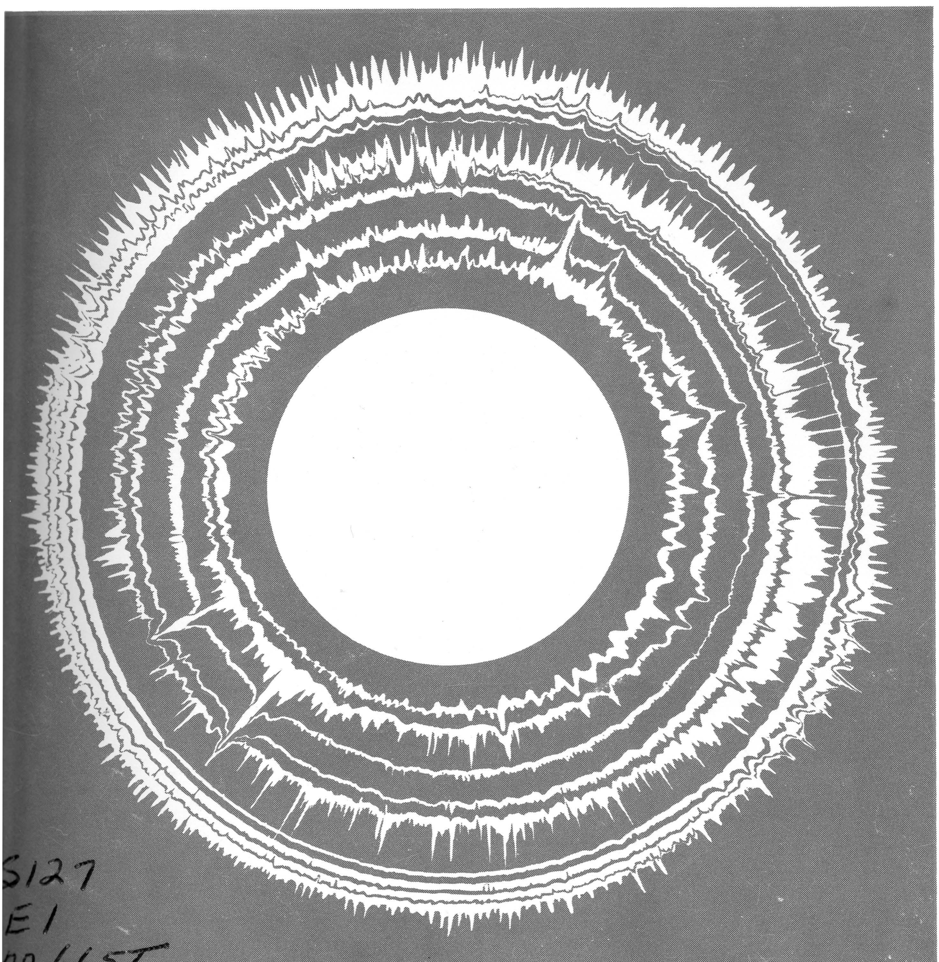
Bulletin 665T
February 1979

West Virginia University
Agricultural and Forestry Experiment Station



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Acknowledgments

The original data for Point Pleasant and Wardensville were collected by W. H. Dickerson. His work was supported by funds allocated under the Hatch Act in connection with Northeast Regional Research Projects NE-35 and NE-69. The data for Kearneysville were collected by V. J. Valli under the auspices of the National Weather Service. Data reduction and analysis efforts were supported by the Division of Forestry.

West Virginia University
Agricultural and Forestry Experiment Station
College of Agriculture and Forestry
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Morgantown

789–2571

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Global Radiation in West Virginia

R. Lee, D. G. Boyer, V. J. Valli, and W. H. Dickerson

INTRODUCTION

Solar radiation is the only significant source of energy to the planet Earth. Energy from the sun has been stored gradually in the earth's crust over the ages, but since the normal rate of storage is small compared to the modern rate of extraction, eventual exhaustion of the reserve appears to be inevitable. In order to avoid the consequences of exploitation, and the environmental hazards that accompany the consumption of fossil fuels, more direct methods of solar energy utilization will be required.

The earth-atmosphere system receives energy from the sun as a continuous electromagnetic flux at an average rate of 173 trillion kilowatts, or 1.94 cal/min cm^2 of cross-sectional area (Thekaekara, 1970). At a given point on the terrestrial surface, the flux density (power/area) of solar radiation is a double periodic function engendered by the earth's simultaneous rotation and revolution about the sun. Superimposed are two important screening functions: (1) atmospheric gases and colloidal substances with relatively constant effects, and (2) moisture clouds with highly unpredictable short-term effects.

The earth's atmosphere reflects about one-third of the total solar flux, on the average, and absorbs about one-fifth, so that only about one-half or less actually irradiates the surface. The atmosphere diffuses and scatters part of the solar beam with the result that, at the surface, solar energy is manifest both as *direct* (point source) and diffuse (hemispherical) *sky* radiation. The total flux (direct plus sky radiation) on an unobstructed horizontal plane at the surface is called *global* radiation.

Under clear skies, or constant atmospheric conditions, the flux density of global radiation at any site is highly correlated with the *potential* (extraterrestrial) flux. Potential radiation for a horizontal surface is a known function of season (solar declination), time of day, and latitude; the mathematical solutions are useful in defining upper limits, and as a point of departure, in evaluating screening effects. Global radiation can be estimated approximately as a function of potential radiation and atmospheric parameters (turbidity, path length, and relative cloudiness), but where accuracy is important there is no adequate substitute for direct observation.

Global radiation is measured at numerous stations throughout the world, especially in more highly developed areas. In the United States there are about 100 stations that report daily totals in langleys (ly, energy/area) or other units (1 ly = 1 cal/cm^2 = 3.69 BTU/ft^2 = 4.19 J/cm^2 = 11.6 W-hr/m^2), and about half as many that report hourly totals. None of the national network stations is in West Virginia.

Maps showing the world-wide distribution of monthly and annual means of global radiation were published by Budyko (1956), Ashbel (1961), and Lof *et al.* (1966). More detailed maps for the United States were developed by Fritz (1949), Fritz and MacDonald (1949), and the U.S. Weather Bureau (1968). Becker and Boyd's (1957) evaluation of solar radiation availability in the United States became a standard reference in engineering practice.

Mean monthly, seasonal, and annual values of global radiation for particular climatological provinces can be interpolated from maps, or estimated using empirical equations based on correlations with mean cloudiness or relative sunshine duration. Approximations of this sort for typical West Virginia conditions were reported by Chang *et al.* (1977), but the data are deficient in several respects. Atmospheric conditions vary considerably within a mountainous region; also, from theoretical considerations, global radiation under clear skies would be expected to increase directly with elevation in the State (about 1 percent per 100 meters), and inversely with latitude (about 1 percent per degree).

Mean values of global radiation are useful as climatological indices and for other reasons, but more detailed information is required to design efficient solar energy collection systems. In particular, the extremes, frequency distributions, and seasonal and interdiurnal variability are important design parameters. It is also helpful for many purposes to characterize daily cycles of global radiation, and the relative contributions of hourly to daily totals.

The purpose of this bulletin is to summarize available global radiation data for West Virginia, to provide statistical parameters that describe the temporal variability of global radiation at three stations, and to elaborate methods for estimating the solar climate at other locations in the State.

METHODS

Apparently there were no continuous observations of global radiation in West Virginia prior to 1956 when the late Professor W. H. Dickerson established a station at Reymann Memorial Farms near Wardensville; in 1960 he established a second station at the Ohio Valley Experiment Station near Point Pleasant. A third station, at the University Experimental Farm near Kearneysville, was added to the network in 1963 by Dr. V. J. Valli. The terrestrial coordinates of these stations are listed in Table 1 along with the corresponding periods of record for which data are analyzed in this report.

Table 1 shows that all three stations lie approximately at the 39th parallel; but Kearneysville and Wardensville are in the rainfall shadow area east of the Appalachian Divide, whereas Point Pleasant is at the western border of the state along the Ohio River. The range of station elevations is only 125 meters, but the elevation at Wardensville is more than 100 meters greater than at the other stations. Some pertinent climatological data for each station, based on the periods of radiation observations, also are given in Table 1.

Table 1. Terrestrial Coordinates, Periods of Record, and Pertinent Climatological Summaries[a] for Global Radiation Stations in West Virginia

Item	Kearneysville	Point Pleasant	Wardensville
Latitude (degrees)	39.39	38.92	39.10
Longitude (degrees)	77.88	82.07	78.58
Elevation (meters)	168	190	293
Period of record	4/63-6/69	8/60-1/70	7/56-10/71
Total record days	2280	2660	4966
Mean annual precipitation (mm)	826	929	837
Mean number of precipitation days/yr	104	130	108

[a]Based on the listed observation periods for global radiation.

The instruments used at Point Pleasant and Wardensville were Eppley pyranometers (16-junction, 180° "pyrheliometers"), standard radiometers in the National Weather Service network; at Kearneysville, records were obtained using a bimetallic pyranograph ("pyrheliograph"). The recording charts were integrated graphically to obtain hourly totals (true solar time) for each day at the first-named stations, and daily totals at Kearneysville. The data were punched on IBM cards, screened for errors, and transferred to magnetic tape for computer analysis.

RESULTS

There were some short gaps in the instrumental records during periods of recalibration and repair, and as a result of temporary instrument malfunction or failure. No attempt was made to estimate missing data because the total number of record days at each station was large (Table 1) and well distributed throughout the year; the total numbers of observation days by months are listed in Table 2. The periods of record among the stations overlap but are not identical.

Daily Totals

Record statistics. Table 2 is a summary of simple statistics based on daily totals of global radiation for entire observation periods. The monthly and annual means are useful in characterizing local solar climate, but it is obvious from Table 2 that individual daily totals exhibit considerable dispersion. For example, the range of daily totals by months is invariably greater than the monthly mean; standard deviations vary from about 30 percent of the means for summer months to about 50 percent in winter.

The usefulness of the standard deviations given in Table 2 is in doubt because, in some instances, the distribution of daily totals is badly skewed. The signs of the coefficients of skewness (Table 2) indicate skew direction: a positive sign indicates a greater than normal proportion of lower radiation totals, and a negative sign a greater than normal proportion of higher totals. Figure 1 shows the highly significant (>99 percent probability) negative skew of daily global radiation totals during June at Wardensville; statistically insignificant (<95 percent probability) or positive skewness is restricted to the distributions for colder months.

Frequency distributions. The relative frequencies of various levels of daily global radiation totals are listed in Table 3 for the three West Virginia stations. The non-normality of the distributions is most apparent during the warmer months when there is a disproportionate share of higher values. During winter months when the daily totals are restricted to narrower ranges, or when the year is considered as a whole, relative frequencies for the various categories exhibit less variability.

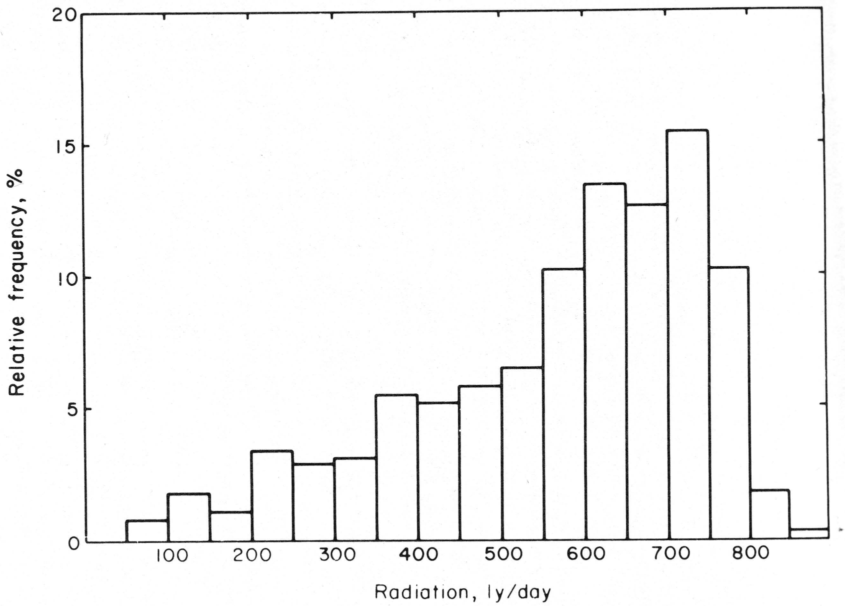


Figure 1. Relative frequency distribution of daily totals of global radiation during June at Wardensville.

Table 2. Daily Totals of Global Radiation (ly/day) at Stations in West Virginia

Item	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Kearneysville													
Highest	458	498	634	750	799	825	774	767	653	645	374	292	825
Mean Max	354	464	600	657	748	752	703	680	581	514	341	280	800
Mean	201	278	366	403	501	548	526	459	386	312	201	160	367
Mean Min	31	43	51	77	111	187	194	200	67	45	28	22	11
Lowest	8	16	32	40	51	106	103	57	5	13	3	6	3
No. Obs.	186	170	186	210	215	203	192	186	180	186	180	186	2280
Std. Dev.	94	124	159	186	176	152	132	130	157	129	93	80	189
Skew Coeff.	-0.21	-0.33	-0.42	-0.26	-0.64	-0.78	-0.81	-0.31	-0.82	-0.50	-0.39	-0.14	0.07
Point Pleasant													
Highest	354	443	550	667	738	734	773	640	603	466	338	287	773
Mean Max	304	396	514	607	674	690	694	593	523	409	290	242	718
Mean	166	207	287	356	477	512	485	444	343	276	155	125	320
Mean Min	25	34	61	69	158	194	154	189	82	77	23	25	17
Lowest	13	18	33	47	65	140	78	99	25	35	16	12	12
No. Obs.	209	191	230	213	238	252	209	199	209	223	252	235	2660
Std. Dev.	90	115	149	169	156	137	135	115	138	104	84	73	184
Skew Coeff.	0.05	0.13	-0.14	-0.11	-0.73	-0.82	-0.64	-0.83	-0.62	-0.57	0.07	0.25	0.18
Wardensville													
Highest	339	534	646	763	798	860	790	726	658	549	396	294	860
Mean Max	337	470	608	700	768	798	753	682	614	500	349	272	801
Mean	199	263	363	437	519	571	525	487	408	320	199	162	370
Mean Min	43	50	68	74	127	161	161	200	88	50	31	29	25
Lowest	16	26	29	42	75	72	74	77	39	25	17	19	16
No. Obs.	397	366	439	403	407	382	396	424	463	452	425	412	4966
Std. Dev.	90	134	169	195	192	175	159	136	155	135	96	77	199
Skew Coeff.	-0.15	-0.12	-0.26	-0.48	-0.56	-0.85	-0.62	-0.59	-0.67	-0.53	-0.23	-0.01	0.16

Table 3. Relative Frequency (%) of Various Levels of Daily Global Radiation Totals

Daily total, ly ≥	<	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Kearneysville														
	50	8.1	2.9	1.6	1.4	–	–	–	–	5.0	3.8	7.8	8.1	3.1
50	100	11.3	8.2	5.4	5.2	2.8	–	–	1.1	2.2	4.3	12.8	19.9	6.0
100	150	10.2	10.0	6.4	6.7	1.9	1.0	1.0	1.1	3.9	6.4	8.3	19.3	6.2
150	200	14.0	7.7	3.8	6.7	2.8	2.9	1.0	0.5	6.7	6.5	13.3	14.0	6.5
200	250	18.8	9.4	9.7	2.8	3.3	2.0	3.6	3.2	2.8	6.5	18.9	23.1	8.5
250	300	26.9	10.6	5.9	6.7	4.6	1.0	1.6	4.3	4.4	12.9	27.2	15.6	9.9
300	350	8.1	19.4	7.5	6.7	5.1	5.4	3.6	8.1	7.2	13.4	9.5	–	7.7
350	400	1.6	11.8	9.7	10.0	3.7	2.5	4.2	11.8	11.1	14.5	2.2	–	6.8
400	450	0.5	13.5	12.4	10.0	9.8	8.9	8.3	15.6	10.5	19.4	–	–	9.1
450	500	0.5	6.5	11.8	9.0	10.2	9.4	12.5	16.1	19.4	9.7	–	–	8.8
500	550	–	–	15.0	8.6	9.8	10.8	16.2	12.4	16.7	2.1	–	–	7.8
550	600	–	–	9.7	5.7	12.1	12.3	14.6	11.8	7.8	–	–	–	6.4
600	650	–	–	1.1	12.9	11.6	16.7	18.8	8.1	1.7	0.5	–	–	6.3
650	700	–	–	–	6.7	11.2	13.8	8.9	4.3	0.6	–	–	–	4.0
700	750	–	–	–	0.5	7.4	9.3	4.7	0.5	–	–	–	–	2.0
750	800	–	–	–	0.5	3.7	2.5	1.0	1.1	–	–	–	–	0.8
800		–	–	–	–	–	1.5	–	–	–	–	–	–	0.1

Point Pleasant

	50	12.0	7.3	3.5	0.9	–	–	–	–	1.4	2.2	13.5	19.6	5.1
50	100	17.7	16.8	11.3	6.6	1.7	–	0.5	0.5	5.7	4.9	19.8	25.1	9.3
100	150	13.4	11.5	11.7	6.6	2.1	1.2	0.9	1.0	6.7	9.0	16.3	14.5	8.0
150	200	19.2	14.7	6.9	9.9	4.6	2.0	1.9	3.5	5.3	8.5	15.9	19.6	9.3
200	250	14.8	11.5	7.4	10.3	3.0	1.2	2.9	4.0	6.7	10.3	17.8	17.4	9.0
250	300	16.7	9.9	9.6	4.2	3.0	5.2	4.3	2.5	6.7	14.8	14.7	3.8	8.0
300	350	5.7	13.6	6.5	7.0	6.7	5.5	7.7	9.0	9.6	23.8	2.0	–	7.9
350	400	0.5	11.0	12.2	10.3	9.7	7.5	4.8	8.6	12.4	17.0	–	–	7.7
400	450	–	3.7	15.7	8.0	6.7	5.2	12.0	14.1	22.5	8.1	–	–	7.8
450	500	–	–	10.0	10.8	8.4	9.5	14.3	19.1	15.8	1.4	–	–	7.3
500	550	–	–	5.2	7.5	12.6	12.3	15.8	22.1	4.8	–	–	–	6.6
550	600	–	–	–	12.2	15.5	21.0	11.0	12.1	1.9	–	–	–	6.3
600	650	–	–	–	5.2	16.8	16.3	17.2	3.5	0.5	–	–	–	5.1
650	700	–	–	–	0.5	8.8	10.3	5.3	–	–	–	–	–	2.2
700	750	–	–	–	–	0.4	2.8	0.9	–	–	–	–	–	0.4
750		–	–	–	–	–	–	0.5	–	–	–	–	–	–

Wardensville

	50	4.3	4.1	1.1	1.0	–	–	–	–	0.9	2.7	8.5	8.7	2.6
50	100	15.9	13.1	6.8	5.7	2.2	0.8	1.0	0.7	4.5	6.4	12.5	18.2	7.3
100	150	11.3	10.4	6.8	5.7	3.2	1.8	0.8	0.9	4.5	7.1	12.2	17.5	6.8
150	200	16.6	7.7	6.6	5.2	1.7	1.1	3.0	1.0	2.8	7.1	12.9	18.0	7.0
200	250	16.4	9.0	8.0	4.2	4.2	3.4	2.3	3.1	6.7	7.3	15.5	22.1	8.5
250	300	21.4	10.1	9.6	4.0	5.2	2.9	3.5	5.4	5.2	7.5	20.9	15.5	9.3
300	350	12.6	12.3	6.8	5.9	5.6	3.1	3.8	6.1	6.5	10.4	15.8	–	7.4
350	400	1.5	16.1	5.9	5.5	4.7	5.5	6.0	7.8	8.4	14.4	1.7	–	6.5
400	450	–	10.4	9.4	8.2	6.9	5.2	6.8	12.3	10.2	20.1	–	–	7.6
450	500	–	6.0	8.7	9.2	7.9	5.8	13.3	11.8	17.7	13.5	–	–	8.0
500	550	–	0.8	15.7	9.2	8.3	6.5	11.6	12.0	13.2	3.5	–	–	6.9
550	600	–	–	10.9	10.4	7.9	10.2	11.1	16.0	14.0	–	–	–	6.8
600	650	–	–	3.7	12.9	7.6	13.4	9.8	13.7	4.8	–	–	–	5.4
650	700	–	–	–	9.7	12.5	12.6	13.9	8.0	0.6	–	–	–	4.6
700	750	–	–	–	3.0	15.0	15.4	9.8	1.2	–	–	–	–	3.5
750	800	–	–	–	0.2	7.1	10.2	3.3	–	–	–	–	–	1.7
800	850	–	–	–	–	–	1.8	–	–	–	–	–	–	0.1
850		–	–	–	–	–	0.3	–	–	–	–	–	–	–

For many practical purposes it is useful to tabulate the totals by percentile ranks where, by definition, the n^{th} percentile is the upper level of the lowest n^{th} percentage of the data. The 10, 30, 50, 70, and 90th percentiles of daily global radiation totals at each of the stations are listed in Table 4 by months and the year; differences between the median (50th percentile) and the mean, a measure of non-normality, also are listed. The 90th percentile is a measure of global radiation under clear skies, and the 10th percentile is a measure of the total solar flux under overcast skies.

Annual cycles. It is frequently useful to characterize annual cycles of daily global radiation totals in terms of averages for shorter time periods because 1) monthly periods are asymmetrically arranged with respect to the solar radiation cycle, and 2) monthly averages tend to obscure the annual extremes. Weekly or biweekly averages are more revealing, but the number of such periods is not an integer. For these reasons, and to facilitate comparisons with potential radiation, the year was divided into 15° intervals of solar longitude beginning at the mean time of the vernal equinox (March 21).

Figures 2, 3, and 4 illustrate annual cycles of the daily totals of potential, clear sky (90th percentile), mean, and overcast sky (10th percentile) radiation at the three stations. In general, clear sky radiation in West Virginia appears to be about 70-80 percent of the potential, mean radiation about 50 percent, and overcast sky radiation about 20 percent; there are, however, some differences among the stations in this respect, and some deviations within station cycles that appear to be systematic. Clear sky, mean, and overcast sky radiation as percentages of the potential at various times of the year are listed in Table 5; clear sky radiation tends to be a larger than normal fraction of the potential during the winter half-year, and the mean and overcast sky radiation tend to be larger than normal fractions of the potential during the summer.

Interdiurnal changes. Daily totals of global radiation fluctuate considerably from day to day, and the interdiurnal change (i.e., the absolute difference between the successive calendar days) is apparently a random variable. Normality tests indicated that interdiurnal changes follow a normal probability distribution, so that standard deviation is an adequate measure of variability. It also is known that, in general, "the frequency distribution of interdiurnal changes stabilizes rapidly, so that means and standard deviations become essentially constant with only five years of data" (Landsberg, 1968).

The monthly and annual means, and standard deviations, of the interdiurnal changes of daily global radiation totals at the three West Virginia stations are listed in Table 6. At all three stations, interdiurnal changes are greatest in April and smallest in December, and the seasonal trends between

Table 4. Percentiles (ly/day) of Daily Global Radiation Totals

Percentile rank	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Kearneysville													
10th	66	90	125	114	228	320	342	299	133	109	60	53	108
30th	152	203	273	300	431	492	469	398	341	257	152	110	247
50th (median)	222	304	395	425	522	574	545	466	431	338	224	165	365
70th	264	355	482	526	622	641	612	523	482	403	260	222	482
90th	300	425	552	634	704	710	672	625	549	452	309	266	628
Median-mean	21	26	29	22	21	26	19	8	45	26	23	5	−2
Point Pleasant													
10th	45	56	69	123	231	303	294	261	119	115	41	34	73
30th	101	127	171	228	393	462	433	402	285	231	92	64	190
50th (median)	168	184	296	373	516	550	503	466	383	300	151	110	309
70th	228	281	402	473	587	597	572	519	433	344	215	178	436
90th	284	355	476	575	645	661	642	569	492	399	262	227	581
Median-mean	2	−23	8	17	39	38	17	22	40	24	−5	−15	−11
Wardensville													
10th	70	74	120	118	223	300	290	291	150	109	55	55	102
30th	148	162	253	342	430	501	461	422	340	245	132	108	239
50th (median)	206	272	385	475	549	618	542	503	451	357	214	165	359
70th	266	360	501	586	668	691	633	579	512	413	269	225	495
90th	306	425	570	665	736	755	708	647	583	473	315	260	649
Median-mean	7	9	22	37	29	47	17	16	43	37	15	4	−11

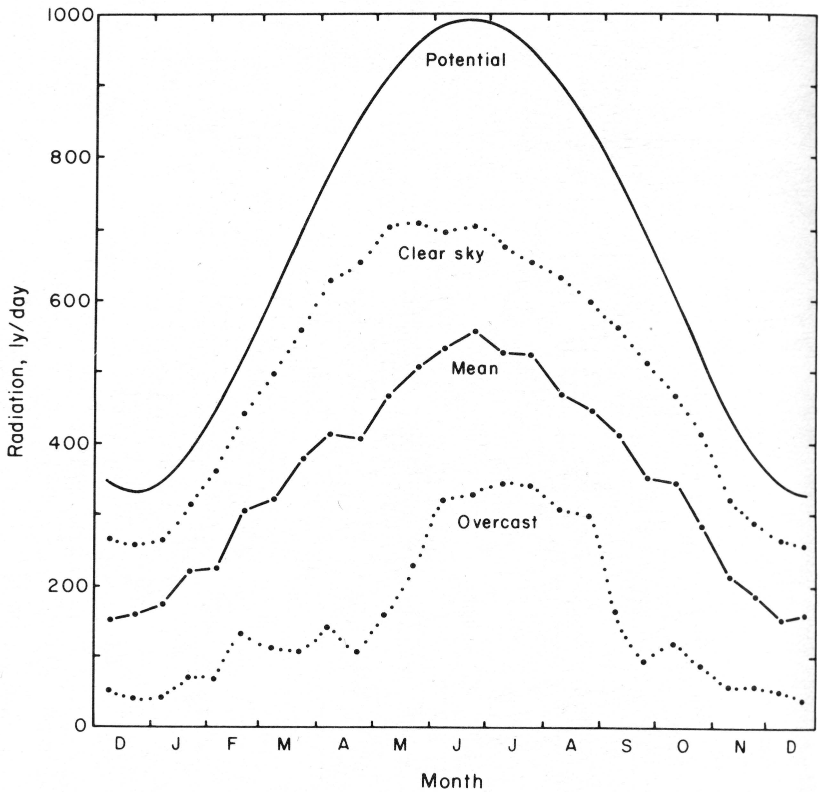


Figure 2. Annual cycles of mean daily global radiation total (Kearneysville).

these extremes are relatively uniform and consistent among the stations. The magnitudes of the mean interdiurnal changes vary from about 25 percent of mean global radiation in summer to about 50 percent in winter; the standard deviations are relatively constant at about 80-90 percent of mean interdiurnal changes.

Yearly variations. All the preceding analyses were based on data for entire observation periods as given in Table 1. Monthly and annual means of daily global radiation totals vary among years, however, and the magnitudes of year to year variations may be important design criteria. Some pertinent statistics are listed in Table 7; only months and years with virtually complete records (less than 10 percent missing data) were included in the analyses.

The monthly means vary considerably from year to year, and the larger absolute variations (ranges) tend to occur during spring and autumn. Most of the lowest and highest means for individual months differ significantly (in the

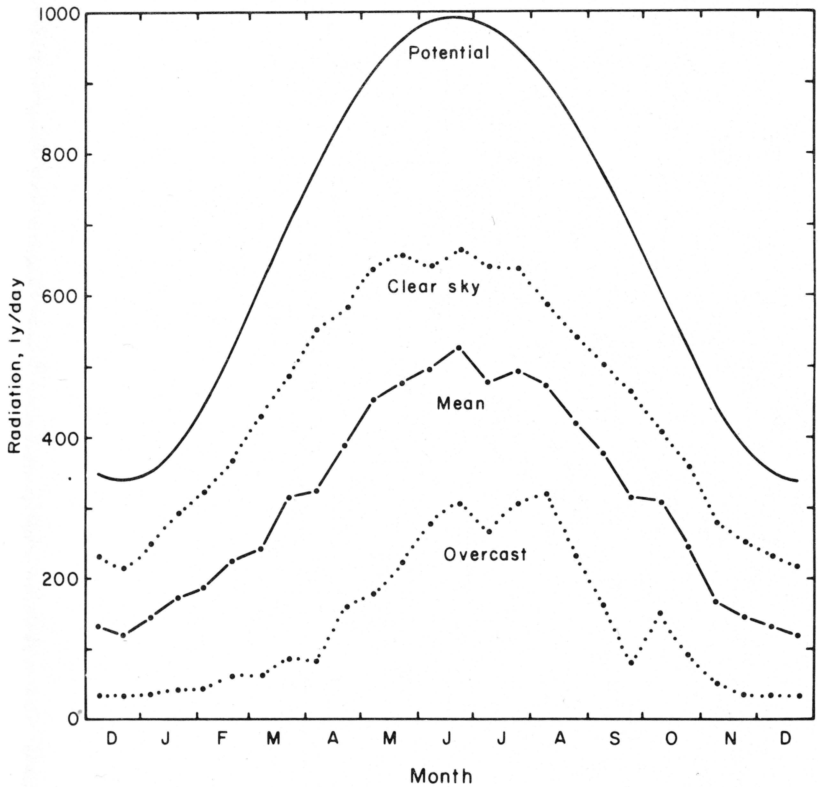


Figure 3. Annual cycles of mean daily global radiation totals (Point Pleasant).

statistical sense, at the 95 percent probability level) from the corresponding record means. Maximum absolute deviations of monthly means vary from less than 10 percent of record means during some of the summer months to 30 percent or more during other seasons.

Hourly Totals

Record statistics. Mean hourly totals of global radiation by months for entire observation periods at two stations are listed in Table 8. There are wide variations in the hourly totals from day to day, of course, as a result of random changes in cloud cover screening effects. Nevertheless, mean hourly totals by months are relatively stable from year to year; for hourly totals closest to noon, maximum absolute deviations of monthly means for individual years vary from about 10 percent of long-term means during summer months, to 30 percent or more during late winter.

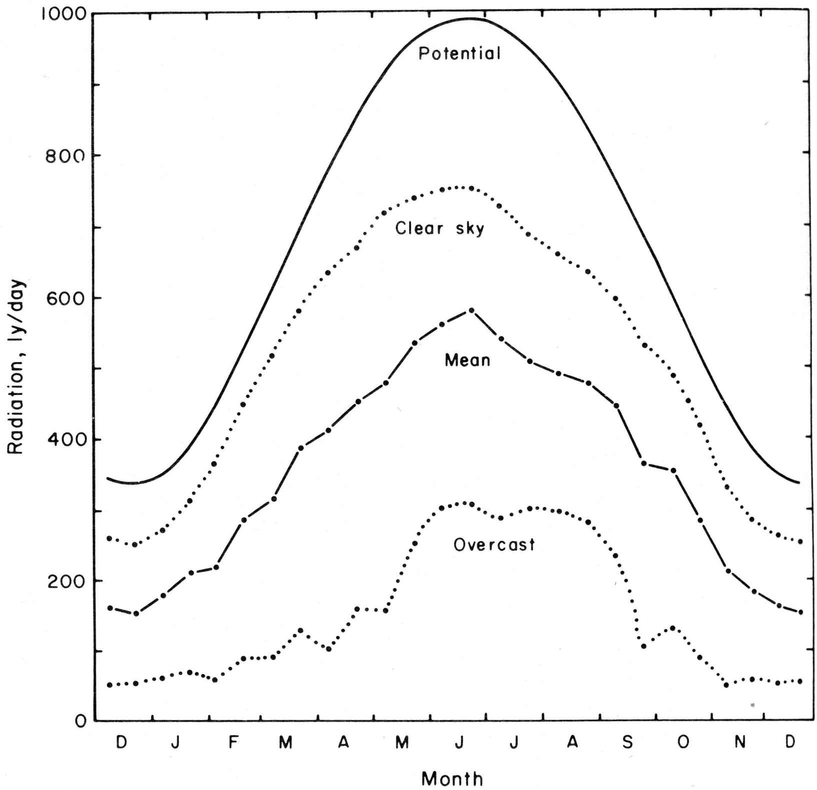


Figure 4. Annual cycles of mean daily global radiation totals (Wardensville).

The lowest recorded hourly totals of global radiation are virtually zero for all hours; this means that the range of hourly totals for any hour is approximately equal to the maximum recorded values. Mean maximum hourly totals of global radiation by months at two stations are listed in Table 9. During midday periods, ± 3 hours of solar noon, the mean values (Table 8) are typically about 60 percent of the mean maxima (Table 9) in winter, and about 70 percent in summer.

Frequency distributions. The frequency distribution of hourly totals of global radiation for a given hourly interval is characteristically skewed. Skew coefficients of the distributions for hourly intervals and selected months at Wardensville are listed in Table 10; most of the coefficients are statistically significant at the 95 percent probability level. The frequency distributions invariably manifest negative skew for hourly intervals during midday, and positive skew for intervals nearer to sunrise and sunset.

Table 5. Clear Sky (CS), Mean (M), and Overcast Sky (OS) Radiation as Percentages of Potential (Extraterrestrial) Radiation

Period	Kearneysville			Point Pleasant			Wardensville		
	CS	M	OS	CS	M	OS	CS	M	OS
Spring	76	53	21	69	48	20	79	55	22
Summer	71	54	31	66	50	27	75	56	31
Autumn	77	51	16	66	42	14	77	51	16
Winter	81	54	17	71	42	10	82	52	17
Year	76	53	21	68	46	18	78	54	22

Table 6. Interdiurnal Changes (ly/day) of Daily Global Radiation Totals

Period	Kearneysville		Point Pleasant		Wardensville	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Jan	87	69	90	71	86	69
Feb	107	96	121	96	137	105
Mar	156	125	136	115	169	134
Apr	181	151	166	134	197	157
May	164	136	143	124	178	141
June	123	114	119	114	157	137
July	129	112	125	113	161	127
Aug	124	98	114	102	137	107
Sept	113	106	99	93	124	111
Oct	108	101	84	74	112	103
Nov	81	67	75	60	95	74
Dec	81	61	70	57	80	60
Year	123	112	111	103	136	120

Table 7. Means and Ranges of Average Daily Total Global Radiation (ly/day)

Statistic	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Kearneysville													
Record years	6	6	6	7	7	6	6	6	6	6	6	6	5
Record mean	210	278	366	403	501	548	530	459	386	312	201	160	368
Lowest mean	166	197	357	312	441	499	468	383	255	289	149	145	346
Highest mean	217	322	399	469	573	585	601	538	471	354	236	183	384
Range	51	125	42	157	132	86	133	155	216	65	87	38	38
Max. Dev. %	21	29	9	23	14	9	13	17	34	13	26	14	6
Point Pleasant													
Record years	6	6	8	7	7	8	7	6	7	8	9	7	2
Record mean	176	210	286	356	483	512	484	454	348	280	155	125	334
Lowest mean	134	175	236	278	429	446	446	401	283	216	127	82	313
Highest mean	203	247	349	432	531	568	531	514	415	345	170	152	354
Range	69	72	113	154	102	122	85	113	132	129	43	70	41
Max. Dev. %	24	18	22	22	11	13	10	13	19	23	18	34	6
Wardensville													
Record years	11	10	12	12	12	10	10	12	14	13	13	11	8
Record mean	199	265	364	435	521	578	530	490	407	321	204	159	376
Lowest mean	166	210	252	337	438	520	472	444	347	264	173	130	365
Highest mean	226	307	434	501	569	606	594	519	468	373	238	187	390
Range	60	97	112	164	131	86	122	75	121	109	65	57	25
Max. Dev. %	17	21	31	23	16	10	12	9	15	18	17	18	4

Table 8. Mean Hourly Totals of Global Radiation (ly/hr)[a]

Hour interval, TST	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Point Pleasant													
4-5	-	-	-	-	*	*	*	*	-	-	-	-	*
5-6	-	*	*	1	2	3	2	2	*	*	-	-	1
6-7	*	1	2	6	11	11	9	9	4	1	*	*	5
7-8	1	6	10	15	23	23	20	20	13	7	2	1	11
8-9	8	15	20	26	36	35	32	33	24	18	8	5	22
9-10	16	23	30	35	46	46	44	43	36	29	16	12	31
10-11	23	28	37	42	54	55	53	53	43	37	22	18	38
11-12	28	31	40	43	58	61	57	56	47	42	25	21	42
12-1	28	31	41	45	58	61	57	55	47	41	25	22	43
1-2	25	29	37	44	54	56	55	52	42	37	22	20	39
2-3	19	22	31	38	49	51	50	45	37	31	18	15	34
3-4	12	14	23	29	39	42	41	36	28	21	11	9	25
4-5	4	6	13	20	27	32	30	24	17	10	4	3	16
5-6	*	1	4	10	16	20	19	13	6	2	*	*	8
6-7	-	*	*	2	6	9	9	4	1	*	-	-	3
7-8	-	-	-	*	1	2	2	1	*	-	-	-	*
Wardensville													
4-5	-	-	-	*	1	1	1	*	*	-	-	-	*
5-6	-	*	*	2	4	5	4	3	1	*	*	-	2
6-7	*	1	4	9	14	16	14	11	7	3	1	*	7
7-8	2	5	13	22	28	32	28	25	18	12	5	1	16
8-9	9	15	26	36	41	46	41	39	32	24	13	8	28
9-10	19	26	38	46	51	57	53	51	43	36	22	17	38
10-11	28	36	46	53	58	63	60	58	51	45	30	24	46
11-12	33	41	51	56	61	65	62	61	55	48	33	28	50
12-1	35	42	52	56	62	64	61	60	55	47	33	29	50
1-2	31	38	47	52	58	62	58	56	50	41	28	25	46
2-3	24	31	38	44	50	55	51	48	41	32	20	19	38
3-4	13	21	27	32	40	44	40	36	29	21	11	9	27
4-5	4	10	15	20	28	31	29	24	17	9	3	2	15
5-6	*	2	5	9	16	19	17	12	7	2	*	*	7
6-7	-	*	1	2	6	8	6	3	1	*	-	-	2
7-8	-	-	-	*	1	2	1	*	*	-	-	-	*

[a]Value rounded to nearest integer; * indicates < 0.5 ly.

Table 9. Mean Maximum Hourly Totals of Global Radiation (ly/hr)[a]

Hour Interval, TST	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Point Pleasant													
AM 4-5	-	-	-	-	*	1	*	*	-	-	-	*	*
5-6	*	1	1	4	7	8	6	5	1	*	*	*	3
6-7	1	5	9	15	21	22	19	16	11	5	*	*	10
7-8	5	21	26	32	39	38	34	32	26	19	7	5	24
8-9	20	35	42	49	56	54	51	51	42	33	21	17	39
9-10	34	48	56	62	68	68	68	63	57	47	32	28	53
10-11	46	55	66	74	76	78	79	75	66	55	42	37	62
11-12	51	60	71	77	83	85	85	77	69	60	48	42	67
PM 12-1	51	60	71	79	81	84	83	75	71	61	48	43	67
1-2	48	54	66	75	78	78	84	71	68	55	44	39	63
2-3	38	47	58	67	73	75	76	64	58	47	36	31	56
3-4	26	32	45	53	60	64	62	55	46	36	23	20	44
4-5	13	17	29	38	45	48	50	40	31	21	10	8	29
5-6	3	6	13	22	28	32	35	26	17	5	1	2	16
6-7	*	*	2	7	13	17	18	11	4	*	*	*	6
7-8	*	*	*	1	3	5	5	2	*	-	*	*	1
Wardensville													
AM 4-5	-	-	-	1	2	2	2	1	*	*	-	-	1
5-6	-	*	2	6	10	10	10	6	4	1	*	-	5
6-7	1	3	11	22	27	27	27	22	16	7	2	*	14
7-8	5	16	30	42	47	49	45	40	35	24	13	5	29
8-9	22	37	50	61	65	66	63	58	53	44	29	23	48
9-10	37	52	67	76	78	80	77	72	67	60	47	34	62
10-11	50	65	78	84	88	87	86	81	77	71	54	44	72
11-12	56	72	84	88	91	92	90	87	81	75	58	50	77
PM 12-1	58	71	85	91	93	94	89	89	83	73	57	50	78
1-2	51	65	81	86	90	91	88	83	75	68	51	45	73
2-3	43	54	68	74	81	83	79	75	66	53	40	34	63
3-4	27	39	52	58	69	69	64	57	50	39	24	23	48
4-5	11	21	32	39	48	50	54	40	32	20	9	5	30
5-6	2	7	13	20	30	36	31	25	16	8	1	1	16
6-7	-	1	3	5	12	18	15	8	4	*	*	-	6
7-8	-	-	*	1	3	5	4	1	*	-	-	-	1

[a]Values rounded to nearest integer; * indicates < 0.5 ly.

Table 10. Skew Coefficients[a] of Distributions of Hourly Global Radiation Totals at Wardensville

Hour Interval, TST	Feb	Apr	June	Aug	Oct	Dec	Year
AM 4-5			2.21*				2.74*
5-6		2.51*	1.64*	2.36*			2.35*
6-7	3.54*	1.25*	0.52*	1.11*	2.28*		1.30*
7-8	2.28*	0.43*	-0.20*	0.18	1.09*	3.22*	0.82*
8-9	1.09*	-0.18*	-0.72*	-0.44*	0.17	1.52*	0.38*
9-10	0.30*	-0.41*	-1.02*	-0.75*	-0.33*	0.39*	0.07*
10-11	-0.06	-0.51*	-1.09*	-0.82*	0.59*	0.18	-0.12
11-12	-0.15	-0.49*	-0.88*	-0.74*	-0.66*	0.10	-0.19*
PM 12-1	-0.20*	-0.39*	-0.75*	-0.70*	-0.56*	-0.08	-0.14*
1-2	-0.17	-0.33*	-0.76*	-0.64*	-0.39*	-0.03	0.02
2-3	-0.07	-0.20*	-0.59*	-0.43*	-0.25*	0.09	0.24*
3-4	0.17	-0.03	-0.47*	-0.25*	0.21*	2.55*	0.52*
4-5	0.92*	0.25*	-0.29*	0.03	0.71*	1.96*	0.87*
5-6	2.76*	0.93*	0.73*	1.48*	2.15*		1.40*
6-7		2.26*	1.65*	2.08*			1.99*
7-8			3.52*				3.35*

[a]Star indicates statistical significance at 95% probability level.

Tables 8-10, and the frequency distributions of radiation totals, show that hourly statistics are roughly symmetrical with respect to solar noon. For this reason the relative frequency distributions of various levels of hourly global radiation totals for entire record periods at Point Pleasant and Wardensville, as listed in Table 11, are grouped by hourly intervals symmetric about noon. Similar distributions, for individual months, are given in the Appendix.

Daily cycles. West Virginia is one of the cloudiest regions of the United States; based on state-wide data, the mean number of days per year during which measurable precipitation occurs is greater than in any of the other states (Chang *et al.* 1977). Rapidly changing sky cover conditions are typical, as indicated by the extreme interdiurnal changes of daily global radiation totals (Table 6). The vagaries of weather and solar climate insure that any "average" daily cycle of global radiation must be an abstraction with limited applicability.

Figure 5 illustrates daily cycles of potential, clear sky (90th percentile), mean, and overcast sky (10th percentile) radiation for selected months at Wardensville. The observed data form typical bell-shaped curves; areas under the curves (daily totals) are relatively stable percentages of potential radiation, as shown in Table 5. The consistent form of the cycles illustrated in Figure 5, as well as in Figures 2-4, have suggested methods of estimating global radiation totals and hourly distributions based on certain critical fragmentary data.

Table 11. Relative Frequency (%) of Various Levels of Hourly Global Radiation Totals[a]

Hourly total, ly ≥	<	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
Point Pleasant									
Zero		0.0	0.0	0.0	0.2	3.4	24.0	51.6	83.0
0	10	10.2	12.1	17.0	27.4	46.7	50.3	43.9	16.8
10	20	12.6	13.1	15.1	21.2	19.7	17.2	3.9	0.2
20	30	10.1	12.3	15.7	15.6	15.8	7.0	0.6	0.0
30	40	11.8	13.4	13.9	14.3	10.7	1.3	0.0	0.0
40	50	13.1	12.8	13.3	13.0	3.3	0.2	0.0	0.0
50	60	13.3	13.7	14.7	7.2	0.4	0.0	0.0	0.0
60	70	14.0	14.5	8.8	1.0	0.0	0.0	0.0	0.0
70	80	13.0	7.5	1.2	0.1	0.0	0.0	0.0	0.0
80	90	1.8	0.5	0.2	0.0	0.0	0.0	0.0	0.0
90	100	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0
100		*	0.1	*	0.0	0.0	0.0	0.0	0.0
Wardensville									
Zero		0.0	0.0	0.1	0.1	1.9	22.8	51.9	81.0
0	10	6.9	8.6	12.9	24.1	45.0	50.0	43.3	18.9
10	20	10.8	11.6	14.3	19.8	18.9	16.7	4.2	0.1
20	30	9.5	10.5	13.9	14.1	14.2	7.7	0.6	0.0
30	40	8.9	11.2	13.3	13.3	11.7	2.3	*	0.0
40	50	12.5	13.0	11.7	12.4	6.3	0.4	0.0	0.0
50	60	11.8	11.2	12.1	10.3	1.7	0.1	0.0	0.0
60	70	12.1	13.0	12.3	5.0	0.3	0.0	0.0	0.0
70	80	13.5	12.8	7.8	0.8	0.0	0.0	0.0	0.0
80	90	12.3	7.6	1.5	0.1	0.0	0.0	0.0	0.0
90	100	1.7	0.5	0.1	0.0	0.0	0.0	0.0	0.0
100		*	*	0.0	0.0	0.0	0.0	0.0	0.0

Interval, hours from solar noon (column headings 0-1 through 7-8).

[a]Values rounded to nearest 0.1%; * indicates < 0.05%.

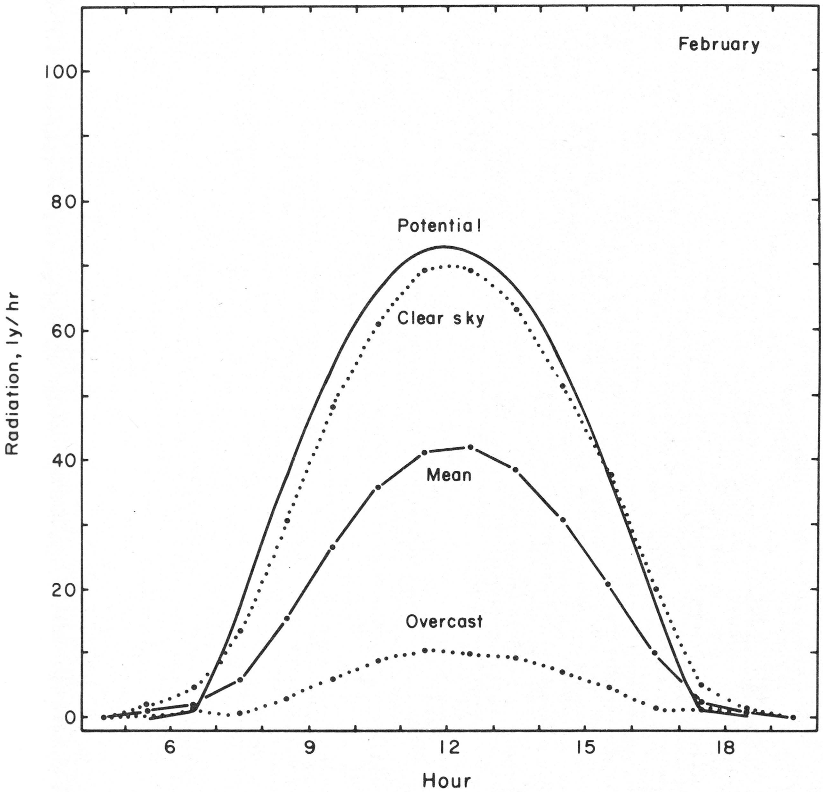


Figure 5. Daily cycles of mean hourly global radiation totals for selected months at Wardensville.

Figure 5 continued

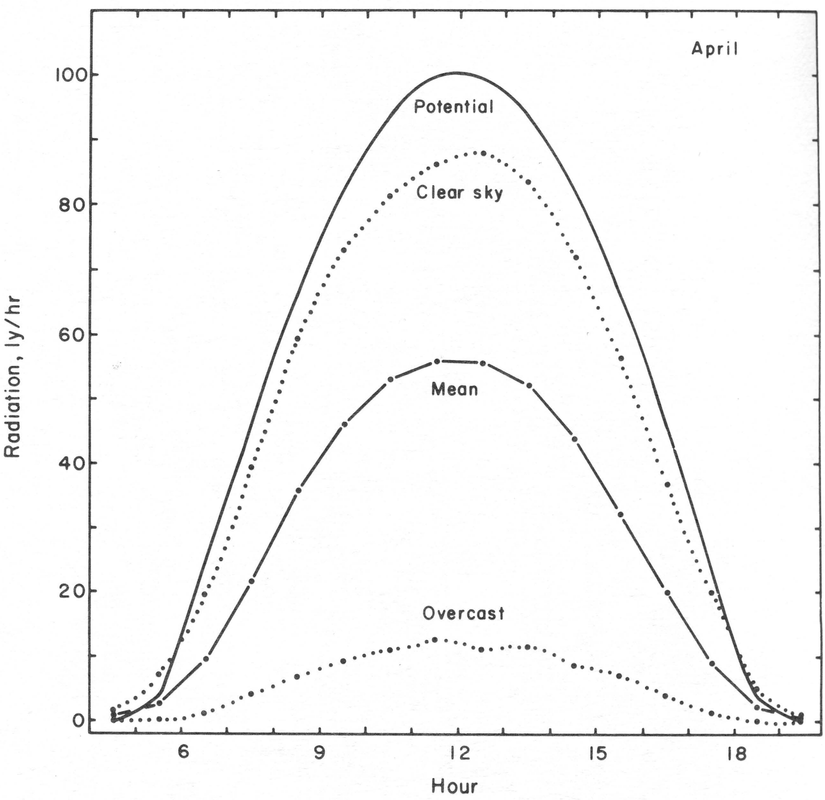


Figure 5 continued

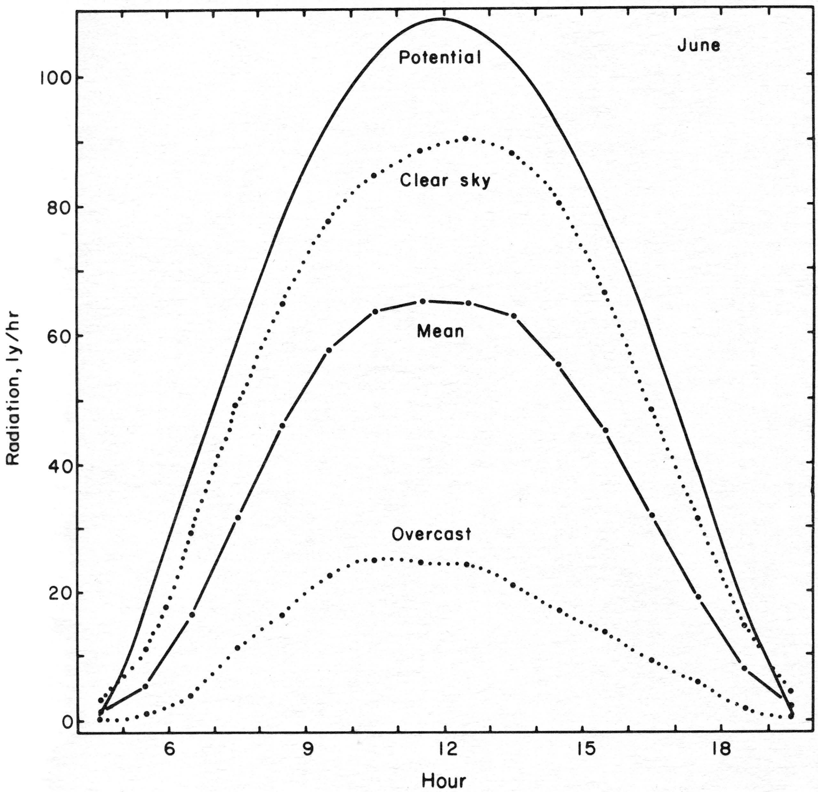


Figure 5 continued

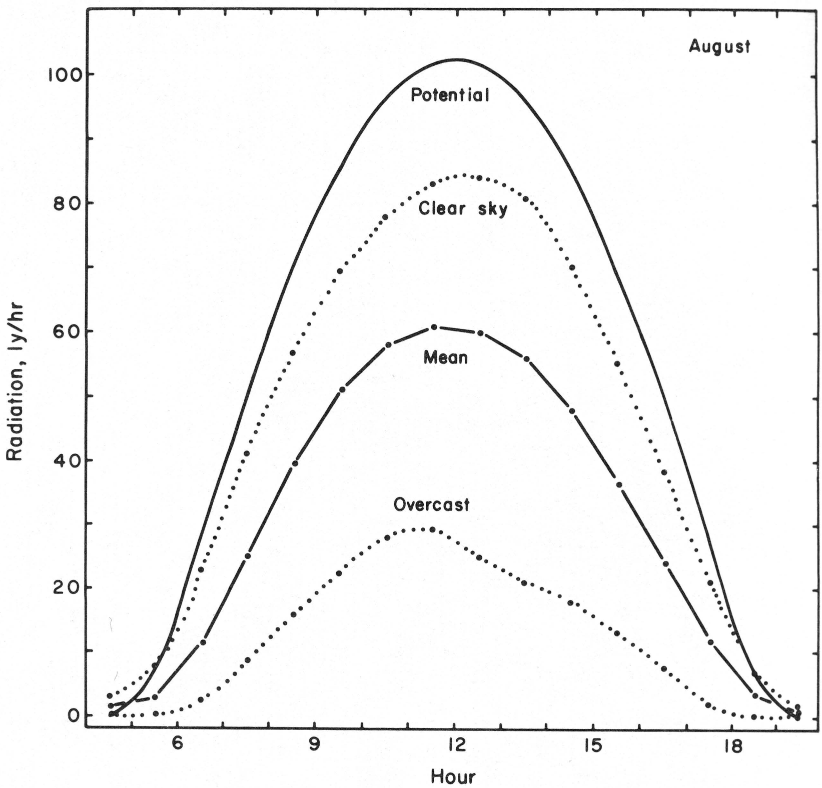


Figure 5 continued

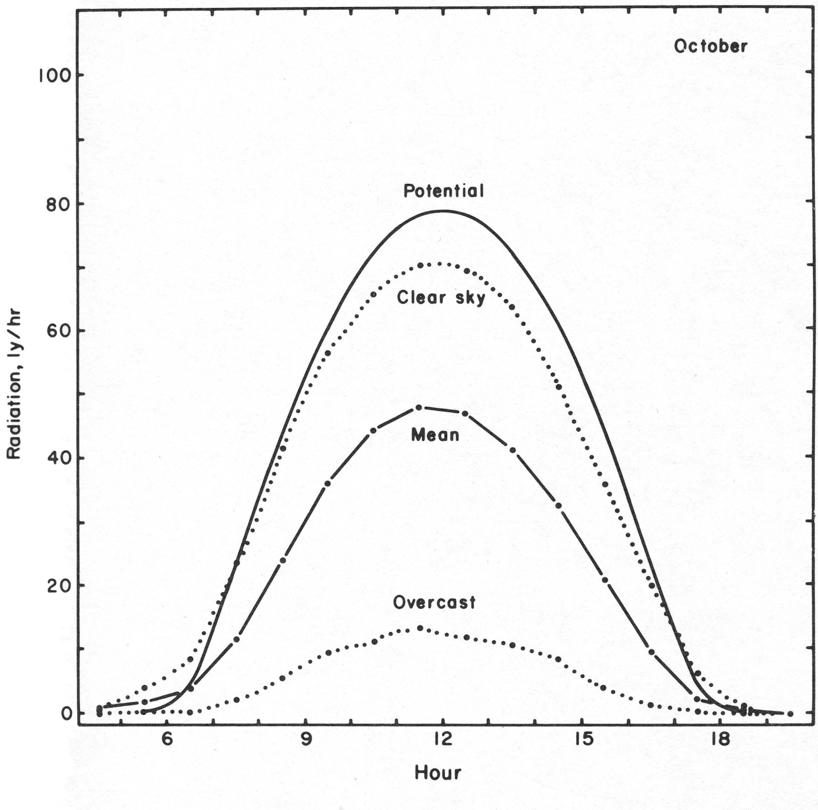
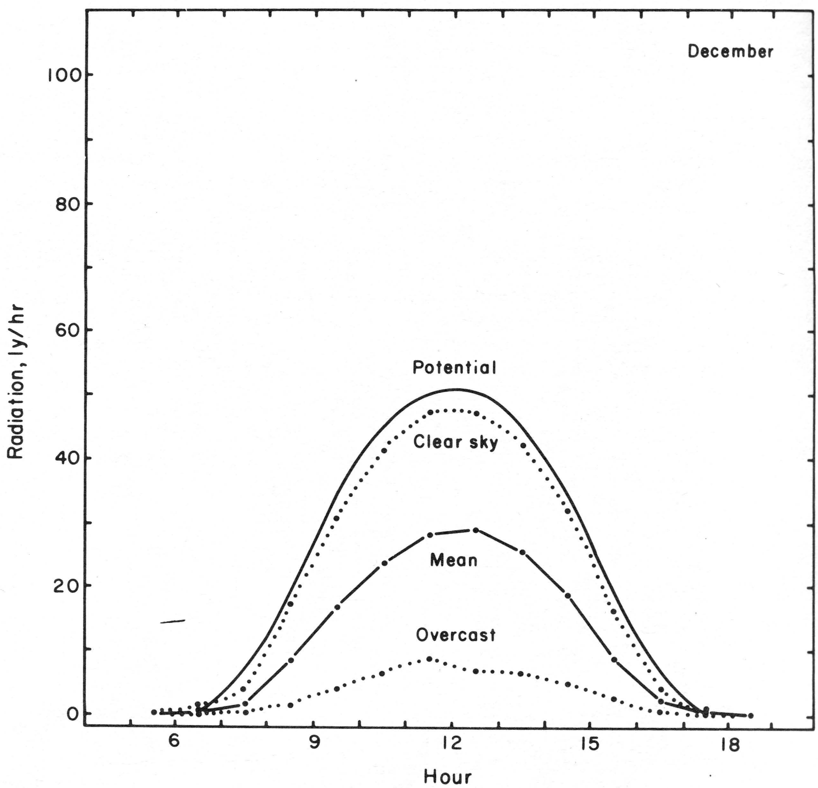


Figure 5 continued



ESTIMATES

Potential Radiation

Potential solar radiation at any station is that which would occur in the absence of an atomosphere. The flux density of potential radiation at any place or time can be calculated mathematically using known geometrical relationships, and the solar constant (1.94 ly/min), as arguments. Potential radiation is an extremely useful parameter because its flux density is highly correlated with the normal (long-term mean) cycles of global radiation.

The daily total of potential solar radiation Sp (in ly/day) on a horizontal surface at a site is given by

$$Sp = (889.23/r^2)\ (\cos\phi \cos\delta)\ (\sin H - H\cos H) \qquad (1)$$

where r is the radius vector (ratio of the earth-sun distance and its mean), ϕ the latitude, δ the solar declination, and H the hour angle ($H = \pi T/12$ radians, and T is the absolute interval of time, in hours, between solar noon and sunrise or sunset). Mean values of Sp by months for West Virginia latitudes are listed in Table 12 along with the corresponding means of r, δ, and day length 2T; the half day length $T = (12/\pi)\cos^{-1}(-\tan\phi \tan\delta)$. The tabular data show that Sp increases inversely with latitude, by about 1 percent per degree on the average, but by about 5 percent per degree in winter; in June, Sp is slightly higher at higher latitudes because day length is greater.

The seasonal distribution of daily totals of Sp is approximately sinusoidal; if the annual mean value $\overline{Sp}$ and amplitude $\alpha = 0.5$ (Sp max – Sp min) of the annual cycle are known, Sp for any day is virtually

$$Sp = (1/r^2)\ \overline{Sp} + \alpha \sin\lambda) \qquad (2)$$

where λ is the solar longitude. Equation 2 estimates Sp in West Virginia with an average error of less than 1 percent; maximum errors, for estimates near the winter solstice, are less than 20 ly/day. Both r and λ can be obtained from a solar ephemeris, or calculated; for all practical purposes

$$r = (1 - e^2)/[1 + e\cos(77.5 + \lambda)] \qquad (3)$$

where the eccentricity of the earth's orbit e = 0.01672, and λ, in degrees, is virtually

$$\lambda = 180\ d/186 \qquad (d \leqslant 186) \qquad (4)$$

$$\lambda = d - 186 \qquad (d > 186) \qquad (5)$$

where d is the number of days following the vernal equinox (March 21). More precise values can be obtained from a solar ephemeris.

At West Virginia latitudes the maximum daily total of potential radiation occurs at the time of the summer solstice (June 22); the maximum is about three times as great as the minimum, which occurs at the time of the winter solstice (December 22). The equinoctial values (March 21 and September 23) are about twice as great as the minimum, or two-thirds of the maximum. Through graphical or numerical integration of Equation 1 (or by examination of Table 12), it can be shown that in West Virginia about two-thirds of total potential radiation for a year occurs during the summer half year ($0° \leqslant \lambda \leqslant 180°$, or April through September).

Equation 1 is the integrated form of an expression for the instantaneous flux density of potential solar radiation sp (ly/min), i.e.

$$sp = (1.94/r^2)(\cos \phi \cos \delta)(\cos h - \cos H) \qquad (6)$$

where h is the specific hour angle ($h = \pi t/12$ radians, and t is the absolute interval of time, in hours, between solar noon and the time in question). Equation 6 can be integrated to obtain total potential radiation for any time interval between sunrise and sunset; the total Sp (hr) for any particular hourly interval is given by

Table 12. Mean Potential Solar Radiation Sp (ly/day) and Day Length 2T (hours) at West Virginia latitudes

Month	Solar declination (δ, degrees)	Radius vector (r)		Latitude (degrees) 37	38	39	40	41
Jan	-20.81	0.9839	Sp	405.6	391.1	376.6	362.1	347.5
			2T	9.8	9.7	9.6	9.5	9.4
Feb	-12.99	0.9879	Sp	526.7	513.5	500.2	486.8	473.2
			2T	10.7	10.6	10.6	10.5	10.5
Mar	- 2.04	0.9948	Sp	686.4	676.3	665.9	655.4	644.6
			2T	11.8	11.8	11.8	11.8	11.8
Apr	9.56	1.0034	Sp	839.0	833.4	827.4	821.3	814.9
			2T	13.0	13.0	13.0	13.1	13.1
May	18.70	1.0110	Sp	942.9	941.6	940.0	938.2	936.2
			2T	14.0	14.0	14.1	14.2	14.3
June	23.15	1.0157	Sp	986.4	987.4	988.2	988.8	989.1
			2T	14.5	14.6	14.7	14.8	14.9
July	21.25	1.0162	Sp	963.5	963.5	963.3	962.8	962.2
			2T	14.3	14.4	14.5	14.5	14.6
Aug	13.84	1.0125	Sp	879.9	876.2	872.3	868.1	863.7
			2T	13.4	13.5	13.5	13.6	13.7
Sept	3.09	1.0054	Sp	746.2	738.0	729.5	720.9	712.0
			2T	12.3	12.3	12.3	12.3	12.4
Oct	- 8.39	0.9969	Sp	587.4	575.5	563.4	551.2	538.8
			2T	11.1	11.1	11.1	11.0	11.0
Nov	-18.21	0.9891	Sp	442/2	428.2	414.1	400.0	385.8
			2T	10.1	10.0	9.9	9.9	9.8
Dec	-22.97	0.9843	Sp	371.0	356.3	341.7	327.0	312.4
			2T	9.5	9.4	9.3	9.2	9.1
Year			Sp	698.8	690.8	682.6	674.3	665.8
			2T	12.0	12.0	12.0	12.0	12.0

$$Sp\ (hr) = (116.4/r^2)\ (\cos\phi \cos\delta)\ (0.9972 \cos h - \cos H) \quad (7)$$

where h is measured to the midpoint of the hour in question. Dividing Equation 7 by Equation 1 yields the ratio R of hourly to daily total potential radiation, or

$$R = 0.1309\ (0.9972 \cos h - \cos H)/(\sin H - H \cos H). \quad (8)$$

Solutions to Equation 8, which apply at all latitudes, are given in Table 13 for day lengths (2T) between 8 and 16 hours. Values of R for any particular day are symmetrical with respect to solar noon. During short (8-10-hour) winter days, from 80 to 90 percent of the total potential radiation occurs within 3 hours of solar noon; at the opposite extreme, during long (14-16-hour) summer days, only about 60 percent of the total occurs over the same midday period.

Table 13. Hourly Percentages (100 R) of Daily Total Potential Solar Radiation

Day length	Hourly intervals from solar noon							
2T, hours	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
8	18.68	16.10	11.13	4.09	-	-	-	-
9	16.77	14.90	11.30	6.21	0.82	-	-	-
10	15.23	13.83	11.11	7.27	2.56	-	-	-
11	13.98	12.88	10.76	7.76	4.09	0.53	-	-
12	12.94	12.06	10.36	7.94	5.00	1.70	-	-
13	12.07	11.34	9.94	7.96	5.52	2.81	0.36	-
14	11.34	10.73	9.54	7.87	5.82	3.54	1.16	-
15	10.71	10.19	9.17	7.73	5.97	4.01	1.97	0.25
16	10.19	9.72	8.83	7.58	6.03	4.31	2.53	0.81

Global Radiation

Global radiation in West Virginia, based on the averages from three stations, is only about 50 percent of potential radiation (Table 5). The percentages vary slightly among the stations, and with the seasons; in addition, there are, of course, extreme variations from day to day as atmospheric conditions fluctuate. Nevertheless, the characteristic annual and daily cycles appear to be highly correlated with potential radiation cycles; to the extent that this is true, the same general formulations (Equations 2 and 8) should prove useful in describing normal annual and daily cycles of global radiation.

Annual cycles. Equation 2 can be written in a form suitable for testing its validity in describing the annual cycle of monthly mean daily global radiation totals Sg; for example,

$$Sg = (1/r^2)\ (\bar{S}g + \alpha \sin\lambda) \quad (9)$$

where Sg is the annual mean, α is taken as half the difference between the

June (maximum) and December (minimum) means, and r and λ are averaged for months (Table 14). Equation 9 was used to estimate monthly means at the three West Virginia stations. Figure 6 illustrates the agreement between observed and estimated cycles at Wardensville.

The observed and estimated monthly means of Sg for West Virginia stations are listed in Table 14 along with the differences (estimated-

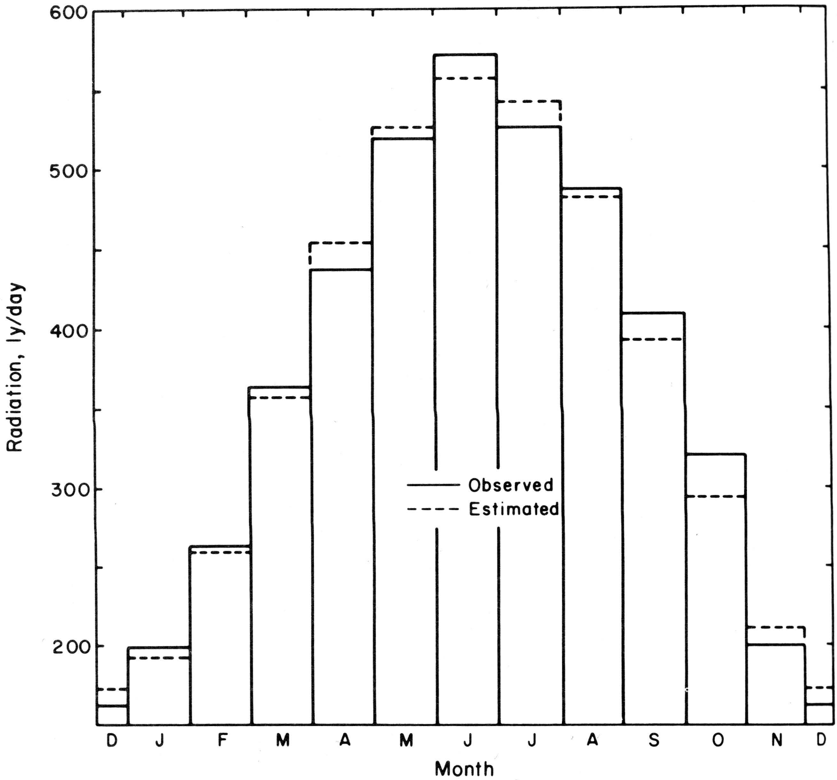


Figure 6. Annual cycles of observed and estimated monthly means of daily global radiation totals at Wardensville.

Table 14. Observed and Estimated Monthly Means of Total Daily Global Radiation (ly/day)

Mean values	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Radius vector, $r(10^4)$	9839	9879	9948	10034	10110	10157	10162	10125	10054	9969	9891	9843
Solar longitude, $\lambda°$	295	325	355	25	54	84	113	143	172	202	233	263
Kearneysville												
Observed, O	201	278	366	403	501	548	526	459	386	312	201	160
Estimated, E	197	262	354	446	513	543	528	472	390	296	217	180
E-O	-4	-16	-12	43	12	-5	2	13	4	-16	16	20
100 (E-O)/0	1.9	5.7	3.3	10.7	2.4	0.9	0.4	2.8	1.0	5.1	8.0	12.1
Point Pleasant												
Observed, O	166	207	287	356	477	512	485	444	343	276	155	125
Estimated, E	149	214	306	399	466	497	482	426	343	249	169	132
E-O	-17	7	19	44	-11	-15	-4	-18	0	-27	14	7
100 (E-O)/0	10.1	3.6	6.4	12.1	2.3	2.9	0.7	4.1	0.0	9.8	9.0	5.6
Wardensville												
Observed, O	199	263	363	437	519	571	525	487	408	320	199	162
Estimated, E	191	259	356	453	524	556	541	481	394	295	211	172
E-O	-8	-4	-7	16	5	-15	16	-6	-14	-25	12	10
100 (E-O)/0	4.0	1.5	2.0	3.6	1.0	2.6	3.0	1.2	3.4	7.8	6.0	6.4

observed). The average error of the estimates for months is about 4 percent of the observed mean; relative errors by months range from 0 to 12 percent. Positive and negative differences appear to be randomly distributed throughout the year, which tends to support the general form of Equation 9.

Daily cycles. The mean hourly totals of global radiation in West Virginia can be described adequately in terms of Equation 8. The agreement between observed and estimated ratios of hourly to daily totals of global radiation is illustrated in Figure 7 for selected months at Wardensville. The estimates are slightly, but consistently, lower than the observed values during midday periods, and slightly higher during some of the early morning and late afternoon hours.

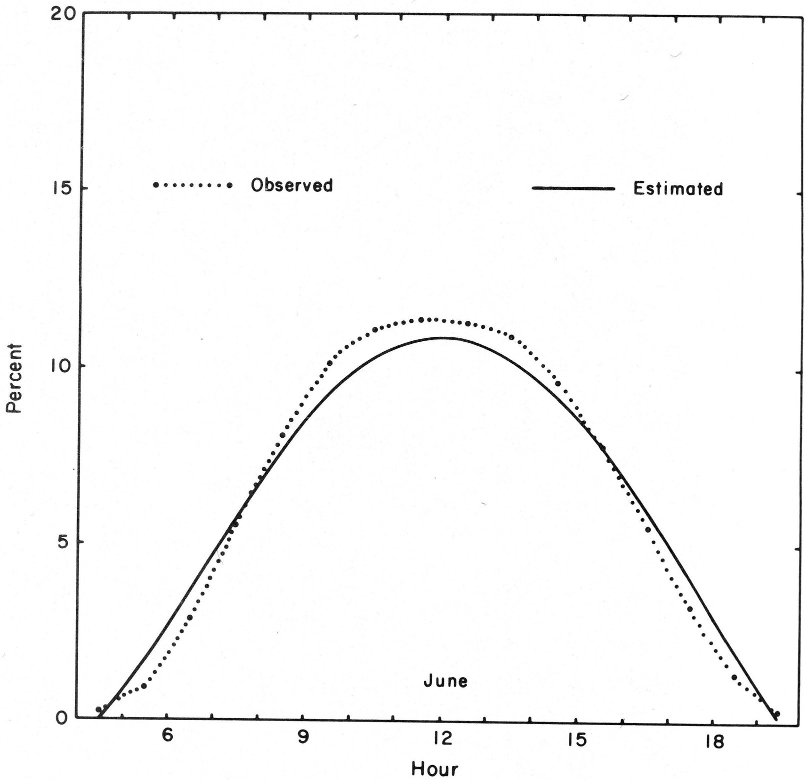
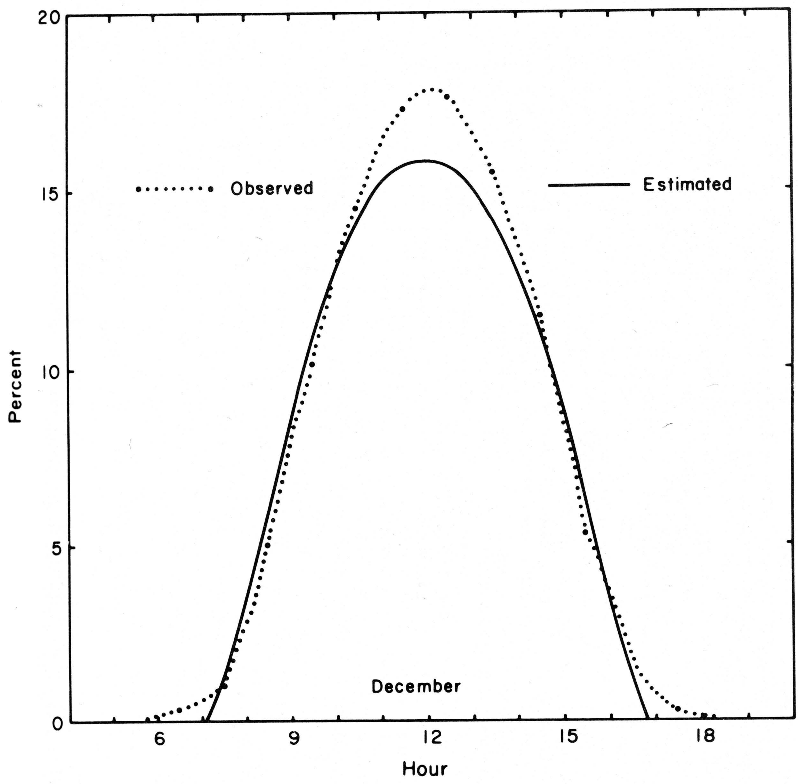


Figure 7. Observed and estimated hourly percentages of daily global radiation totals for selected months at Wardensville.

Figure 7 continued



Hourly radiation totals as percentages of daily totals are illustrated in Figure 8 for both potential solar radiation (100 R, from Equation 8), and observed global radiation at Wardensville. The observed values are monthly means for entire observation periods; the data for hourly intervals symmetrical about noon have been combined. Percentage point differences between observed and potential values for each hourly interval at each station are listed in Table 15; the mean absolute difference for all intervals is about 0.6 of one percentage point, and all of the observed values are within 1.4 percentage points of the potential.

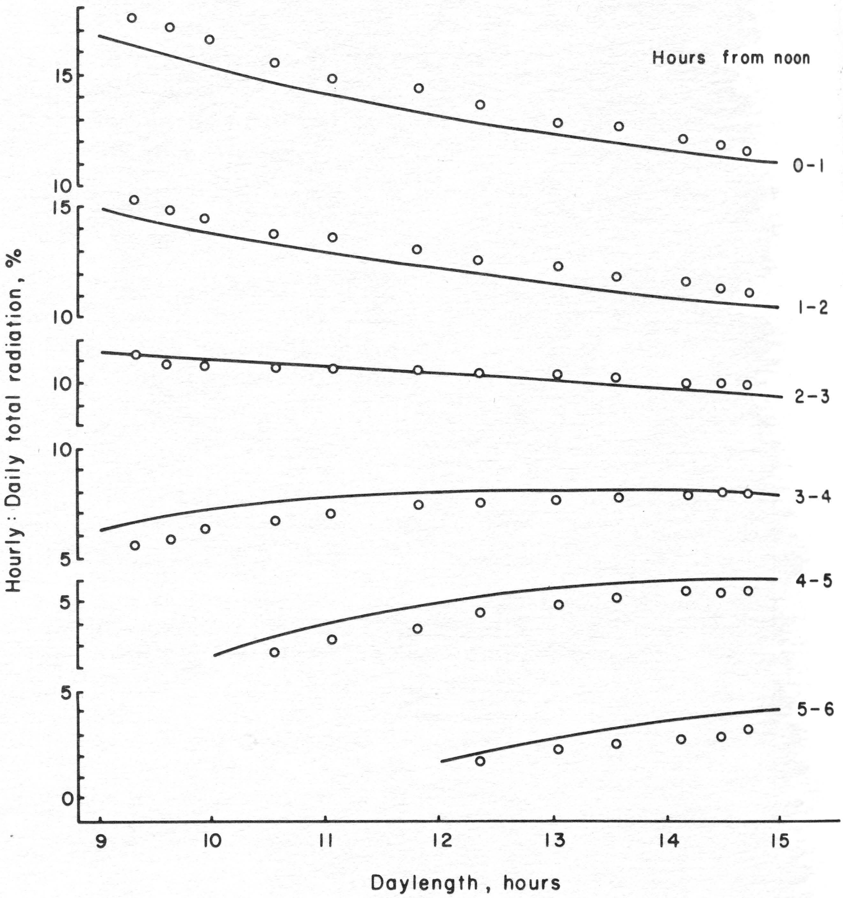


Figure 8. Hourly radiation totals as percentages of daily totals; potential radiation (solid lines), observed global radiation at Wardensville (open circles).

Table 15. Mean and Maximum Differences (Percentage Points) Between Observed and Potential Ratios of Hourly to Daily Radiation Totals

Interval, hours from solar noon	Point Pleasant Mean	Point Pleasant Maximum	Wardensville Mean	Wardensville Maximum
0-1	0.88	1.19	0.91	1.37
1-2	0.59	0.80	0.64	0.73
2-3	0.07	-0.55	0.08	0.56
3-4	-0.52	-1.17	-0.54	-1.40
4-5	-0.74	-1.01	-0.69	-1.01
5-6	-0.74	-0.83	-0.75	-0.87

EXTRAPOLATION

Global radiation has been observed routinely at only three stations in West Virginia (Kearneysville, Point Pleasant, and Wardensville); these stations are all at lower elevations, and all are within 0.4° of the 39th parallel (Table 1). Solar radiation data from other locations in the state are fragmentary at best, consisting of observations obtained over short-time intervals in connection with particular research objectives. One of the purposes of this report is to elaborate methods that might be used, in lieu of observations, to describe the solar climate at other locations.

At numerous stations on earth, mean monthly values of total daily global radiation Sg have been found to be highly correlated with potential radiation Sp. The relationship at Wardensville is illustrated in Figure 9(a); the regression equation

$$Sg = 0.5920Sp - 32.03 \qquad \text{(Wardensville)} \qquad (10)$$

is valid for the range of Sg between about 100 and 600 ly/day. In this relationship, the correlation coefficient squared (R^2) is 0.992, and the average error of the estimate is 3.0 percent of the observed value (maximum error 6.7 percent).

Ordinarily the regression coefficients of Equation 10 will vary from place to place in response to mean atmospheric conditions. For example, at Point Pleasant where precipitation frequency is about 20 percent greater than at Wardensville (Table 1),

$$Sg = 0.5747Sp - 72.66 \qquad \text{(Point Pleasant)} \qquad (11)$$

The relationship is illustrated in Figure 9(b); the correlation coefficient squared (R^2) is 0.978, and the average error of the estimate is 5.5 percent of the observed value (maximum error 13.4 percent).

Because of the variability of the regression coefficients among localities, generalized models frequently include an independent parameter to characterize local climate. Some common forms are:

$$Sg = Sp\ (a + bS) \qquad (12)$$

$$Sg = Sp\ (a - bC) \qquad (13)$$

where S is the relative duration of bright sunshine (i.e., ratio of the mean number of hours of bright sunshine to the possible number), and C is the mean fraction of cloud cover. In West Virginia, sunshine duration data are available for only one station and cloud cover data for only five stations; the available data (Environmental Data Service) are listed in Table 16.

None of the stations listed in Table 16 is east of the Appalachian Divide, so it was not possible to develop models for Kearneysville and Wardensville based on Equations 12 and 13. Huntington and Parkersburg are roughly equidistant from Point Pleasant (about 60 km), and the data from these

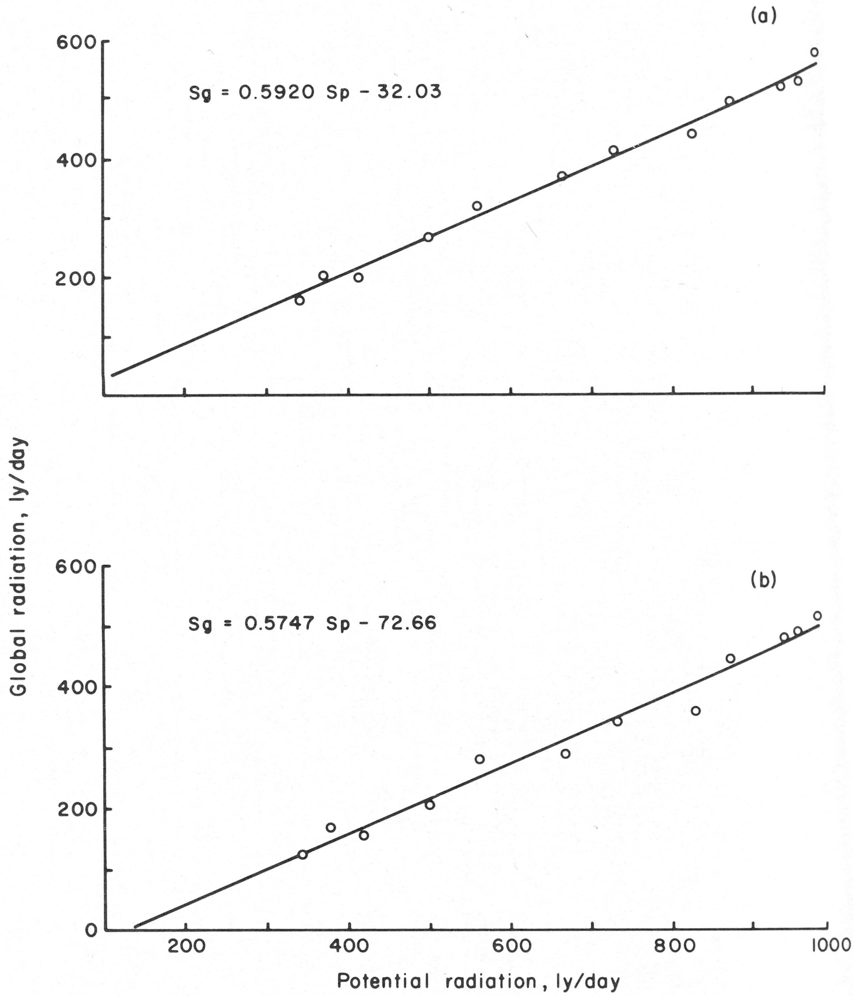


Figure 9. Mean daily global radiation Sg as a function of the potential radiation Sp at a) Wardensville, and b) Point Pleasant. Plotted points are monthly means for the periods of observation.

Table 16. Relative Sunshine Duration and Cloud Cover (Sunrise to Sunset) at West Virginia Stations[a] (Mean Values, in Percent)

Station	Period	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Sunshine duration														
Parkersburg	1962-70	40	41	45	48	58	58	56	58	58	58	34	29	49
	N(73)[b]	31	36	42	49	56	60	62	60	60	54	37	29	48
Cloud cover														
Beckley	1964-71	71	72	72	71	67	69	73	67	62	56	70	77	69
Charleston	N(24)	77	75	74	70	66	65	68	64	61	59	72	75	69
Elkins	N(27)	78	77	75	74	71	70	71	69	66	61	73	78	72
Huntington	1962-70	70	71	73	70	63	63	66	62	61	54	73	76	67
Parkersburg	1962-70	64	64	61	61	54	55	60	53	50	48	69	73	59
	N(71)	73	69	64	60	56	53	50	51	48	52	66	73	60

[a] Latitude $\phi°$, longitude $\lambda°$, and elevation Z(m): Beckley $\phi = 37.8$, $\lambda = 81.1$, $Z = 763$; Charleston $\phi = 38.4$, $\lambda = 81.6$, $Z = 286$; Elkins $\phi = 38.9$, $\lambda = 79.9$, $Z = 594$; Huntington $\phi = 38.4$, $\lambda = 82.6$, $Z = 252$; Parkersburg $\phi = 39.3$, $\lambda = 81.6$, $Z = 187$.

[b] N = normal, or long-term mean, based on number of years in parentheses.

stations were used to develop the models for Point Pleasant. The pertinent statistics are listed in Table 17 along with those developed in connection with other models.

Table 17. Empirical Models for Predicting Monthly Means of Daily Global Radiation Totals (Sg, ly/day) as a Function of Potential Radiation (Sp), Relative Sunshine Duration (S, decimal), and Mean Cloudiness (C, decimal)

Regression equation	Correlation coefficient squared (r^2)	Error of estimate (% of observed value)	
		Mean	Maximum
Kearneysville			
a) $Sg = 0.5469Sp - 9.31$	0.984	4.2	9.0
b) $Sg = 0.8049S_0 - 53.93$	0.955	5.3	15.4
Point Pleasant			
c) $Sg = 0.5747Sp - 72.66$	0.978	5.5	13.4
d) $Sg = 0.8627S_0 - 82.19$	0.962	6.6	16.4
e) $Sg = Sp(0.2227 + 0.4765S)$	0.993	3.0	6.2
f) $Sg = Sp(0.8657 - 0.6524C)$	0.976	5.1	9.8
g) $Sg = S_0(0.3157 + 0.7180S)$	0.984	4.9	6.6
h) $Sg = S_0(1 - 0.5364C)$	0.949	7.7	12.5
Wardensville			
i) $Sg = 0.5920Sp - 32.03$	0.992	3.0	6.7
j) $Sg = 0.7955S_0 - 55.86$	0.977	4.6	9.6

An alternative approach is frequently used in which Sg is related to clear sky radiation S_0. As a rule, S_0 is taken as the mean of "clear day" values of Sg, or slightly lower than the maximum observed values for a period; in this report S_0 is arbitrarily defined as the 90th percentile. Some common expressions for Sg in terms of S_0 are:

$$Sg = S_0 (a + bS) \tag{14}$$

$$Sg = S_0 (1 - bC) \tag{15}$$

The pertinent statistics for Point Pleasant are listed in Table 17 for comparison with other models.

The data of Table 17 show that the monthly means of Sg are highly correlated with potential radiation Sp; in fact, the simple regression models (a, c, and i) are superior to those based on clear sky radiation (b, d, and j). Where relative sunshine duration and mean cloudiness data are available (Point Pleasant), the accuracy of predictions can be improved in some instances. The empirical models developed for Point Pleasant show that, generally speaking, potential radiation Sp and relative sunshine duration S are more efficient parameters than are clear sky radiation S_0 and mean cloudiness C.

It is intuitively clear that relative sunshine duration S and mean cloudiness C at a given station must be negatively correlated, but it is generally true that $S \neq 1-C$ (S and C expressed as decimal fractions). As a rule, the quantity S + C is greater than unity and manifests distinct seasonal variation. Using the long-term monthly means for Parkersburg (Table 16),

$$S = 1.0062 + 0.1100 \sin(n\pi/12) - C \tag{16}$$

where n is the calendar month number; in this relationship the mean error of the estimate is 0.9 percent of the observed S (maximum error 2.3 percent). Apparently, for all practical purposes, S can be estimated from the more common observations of cloud cover C. Whether or not the coefficients in Equation 16 are applicable to other West Virginia stations, however, is debatable.

Global radiation has been observed routinely over significant periods of time at only three stations in West Virginia, and there is at present no completely satisfactory method of extrapolating to other locations. As a first approximation, Equation 10 might be used in conjunction with Equation 1 or Table 12 to estimate mean daily totals east of the Appalachian Divide, and Equation 11 used for estimates in the western zone. Additional accuracy may be achieved where fragmentary local data are available, or where relative sunshine duration or cloud cover have been observed.

Mean cloudiness data were used to estimate monthly means of total daily global radiation Sg at the five western-zone stations listed in Table 16. The best empirical model for the western zone based on mean cloud cover C (f, Table 17), and potential radiation Sp, gave the results listed in Table 18. The validity of this extrapolation rests on the assumption that the effects of cloud cover on global radiation at Point Pleasant are similar to those at the other stations.

At locations in the state where cloudiness data are not available, other crude indices may be helpful. For example, there is a significant degree of correlation between annual mean cloudiness C and precipitation P in West Virginia and surrounding regions; Figure 10 shows that, with a maximum error of about 4 percentage points, C (percent) = 11.16 + 0.0528 P (P in mm/yr). Mean annual cloudiness estimated in this manner may be useful as a rough approximation for comparison with the annual values of mean cloudiness at stations listed in Table 16; characteristic cloud types, and the seasonal variation of cloud cover, limit the usefulness of this extrapolation index.

Table 18. Estimated Monthly Means of Daily Global Radiation Totals (ly/day) at Five West Virginia Stations

Month	Beckley	Charleston	Elkins	Huntington	Parkersburg
Jan	158.7	140.2	135.0	157.5	144.7
Feb	204.2	191.2	182.1	204.2	205.6
Mar	268.7	257.5	251.1	261.7	296.8
Apr	335.9	340.0	317.1	340.0	391.4
May	403.7	409.4	378.4	427.8	470.0
June	410.2	436.2	404.2	449.1	513.9
July	375.2	406.7	387.7	419.2	519.6
Aug	375.9	392.1	362.7	403.4	464.2
Sept	341.2	343.7	317.9	343.6	401.4
Oct	288.3	273.6	263.3	291.8	293.3
Nov	176.4	167.5	161.9	164.5	178.0
Dec	130.7	132.1	122.5	129.5	131.1
Year	287.7	285.8	270.6	294.6	322.3

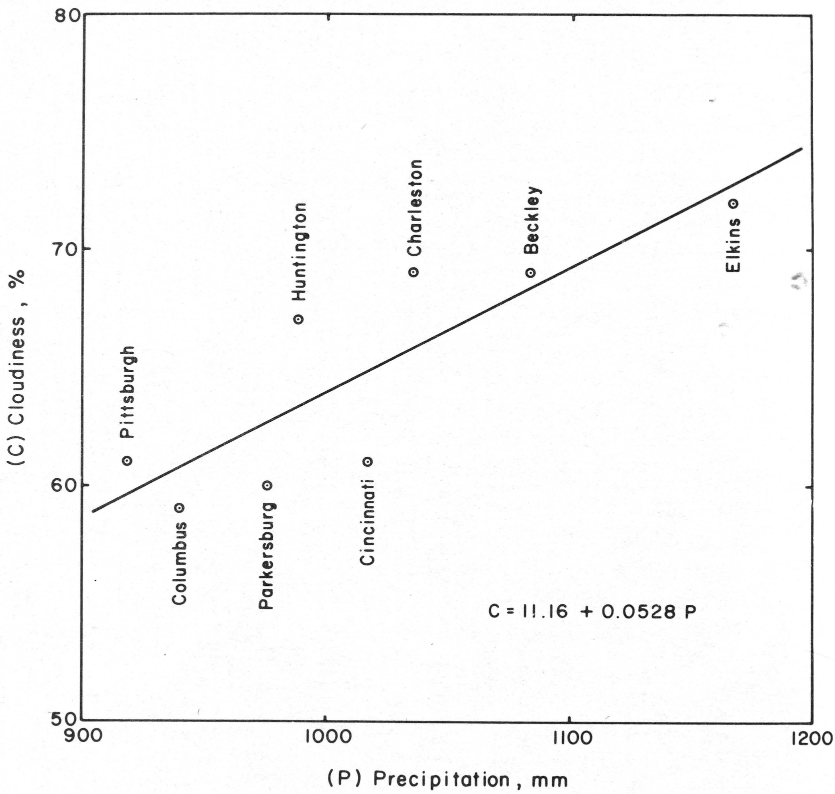


Figure 10. The relationship between mean annual cloudiness and precipitation at stations in West Virginia and surrounding areas.

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APPENDIX

Relative Frequency (%) of Various Levels of Hourly Global Radiation Totals
JANUARY

Hourly total, ly ≥	<	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
		Interval, hours from solar noon							
Point Pleasant									
Zero		0.0	0.0	0.2	0.9	17.4	68.7	94.6	96.3
	10	18.2	21.8	30.0	57.1	76.8	31.3	5.4	3.7
10	20	19.7	20.2	28.3	29.8	5.6	0.0	0.0	0.0
20	30	14.2	19.2	24.8	10.8	0.2	0.0	0.0	0.0
30	40	17.0	23.2	14.3	1.4	0.0	0.0	0.0	0.0
40	50	23.2	13.8	2.4	0.0	0.0	0.0	0.0	0.0
50	60	7.4	1.8	0.0	0.0	0.0	0.0	0.0	0.0
60		0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wardensville									
Zero		0.0	0.0	0.0	0.3	3.8	67.7	99.6	100.0
	10	9.7	13.3	21.8	49.2	93.4	32.3	0.4	0.0
10	20	17.5	18.8	23.5	35.2	2.8	0.0	0.0	0.0
20	30	15.6	15.8	26.2	14.3	0.0	0.0	0.0	0.0
30	40	12.0	19.0	24.0	1.0	0.0	0.0	0.0	0.0
40	50	22.2	27.9	4.4	0.0	0.0	0.0	0.0	0.0
50	60	21.8	5.2	0.1	0.0	0.0	0.0	0.0	0.0
60		1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Relative Frequency (%) of Various Levels of Hourly Global Radiation Totals
FEBRUARY

Hourly total, ly ≥	<	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
		Interval, hours from solar noon							
Point Pleasant									
Zero		0.0	0.0	0.0	0.2	2.1	37.7	84.6	93.4
	10	17.2	19.0	24.8	42.2	78.4	61.6	15.4	6.6
10	20	15.9	17.0	21.6	30.6	14.9	0.7	0.0	0.0
20	30	14.8	18.8	21.2	17.0	4.4	0.0	0.0	0.0
30	40	16.4	12.8	18.6	8.4	0.2	0.0	0.0	0.0
40	50	13.3	19.6	11.3	1.6	0.0	0.0	0.0	0.0
50	60	17.2	11.5	2.5	0.0	0.0	0.0	0.0	0.0
60		5.2	1.3	0.0	0.0	0.0	0.0	0.0	0.0
Wardensville									
Zero		0.0	0.0	0.0	0.2	1.0	35.2	93.2	100.0
	10	9.8	11.5	16.1	32.9	70.1	63.0	6.8	0.0
10	20	15.6	15.5	17.7	25.3	22.2	1.7	0.0	0.0
20	30	11.9	13.7	16.3	21.8	5.4	0.1	0.0	0.0
30	40	8.4	10.6	15.8	15.7	1.1	0.0	0.0	0.0
40	50	8.7	13.7	19.8	3.1	0.2	0.0	0.0	0.0
50	60	15.3	19.2	10.0	0.8	0.0	0.0	0.0	0.0
60	70	23.0	15.1	1.2	0.2	0.0	0.0	0.0	0.0
70	80	7.2	0.7	0.1	0.0	0.0	0.0	0.0	0.0
80		0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Relative Frequency (%) of Various Levels of Hourly Global Radiation Totals
MARCH

Hourly total, ly ≥	<	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
				Interval, hours from solar noon					
Point Pleasant									
Zero		0.0	0.0	0.0	0.0	0.5	10.6	63.0	95.8
	10	11.4	14.4	19.5	25.9	51.4	82.7	37.0	4.2
10	20	16.1	14.8	14.7	22.5	30.2	6.7	0.0	0.0
20	30	9.7	12.8	14.0	20.8	16.0	0.0	0.0	0.0
30	40	9.5	4.6	14.4	20.8	2.1	0.0	0.0	0.0
40	50	8.7	10.2	18.5	9.6	0.0	0.0	0.0	0.0
50	60	15.5	21.6	18.3	0.4	0.0	0.0	0.0	0.0
60	70	26.0	16.4	0.6	0.0	0.0	0.0	0.0	0.0
70		3.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Wardensville									
Zero		0.0	0.0	0.0	0.0	0.1	7.5	57.4	99.4
	10	5.9	8.4	12.3	18.8	44.1	80.3	42.5	0.6
10	20	11.7	11.0	14.6	22.6	29.1	11.2	0.1	0.0
20	30	10.1	12.6	12.2	15.2	18.1	0.9	0.0	0.0
30	40	9.8	8.7	11.1	19.0	7.7	0.1	0.0	0.0
40	50	7.6	8.7	12.4	18.1	0.8	0.0	0.0	0.0
50	60	7.4	10.7	19.3	5.2	0.1	0.0	0.0	0.0
60	70	8.2	17.8	14.9	0.9	0.0	0.0	0.0	0.0
70	80	27.2	19.0	2.7	0.2	0.0	0.0	0.0	0.0
80	90	12.0	3.1	0.5	0.0	0.0	0.0	0.0	0.0
90		0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Relative Frequency (%) of Various Levels of Hourly Global Radiation Totals

APRIL

Hourly total, ly ≥	<	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
		Interval, hours from solar noon							
Point Pleasant									
Zero		0.0	0.0	0.0	0.0	0.0	0.2	18.8	90.4
	10	9.4	10.5	12.8	18.7	33.5	68.8	80.5	9.6
10	20	15.7	11.6	13.8	18.7	25.4	25.4	0.7	0.0
20	30	10.8	10.8	12.1	15.9	26.4	5.6	0.0	0.0
30	40	8.9	12.8	13.3	16.6	12.6	0.0	0.0	0.0
40	50	10.0	9.8	13.0	21.5	2.1	0.0	0.0	0.0
50	60	9.1	10.7	21.4	8.6	0.0	0.0	0.0	0.0
60	70	14.2	23.3	12.8	0.0	0.0	0.0	0.0	0.0
70	80	20.3	10.0	0.7	0.0	0.0	0.0	0.0	0.0
80		1.6	0.5	0.0	0.0	0.0	0.0	0.0	0.0
Wardensville									
Zero		0.0	0.0	0.0	0.0	0.0	1.2	21.4	86.1
	10	7.7	7.6	11.3	15.5	26.4	62.4	76.4	13.9
10	20	10.8	10.4	9.4	12.8	24.2	26.5	2.0	0.0
20	30	6.3	8.7	9.4	13.6	23.2	8.3	0.1	0.0
30	40	8.1	7.5	10.5	14.2	18.0	1.5	0.0	0.0
40	50	6.3	6.3	9.4	18.1	6.9	0.1	0.0	0.0
50	60	8.1	9.7	13.2	19.1	1.2	0.0	0.0	0.0
60	70	8.2	12.9	20.9	6.2	0.1	0.0	0.0	0.0
70	80	15.3	20.8	14.7	0.5	0.0	0.0	0.0	0.0
80	90	25.9	15.5	1.1	0.0	0.0	0.0	0.0	0.0
90		3.3	0.6	0.1	0.0	0.0	0.0	0.0	0.0

Relative Frequency (%) of Various Levels of Hourly Global Radiation Totals

MAY

Hourly total, ly ≥	<	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
		Interval, hours from solar noon							
Point Pleasant									
Zero		0.0	0.0	0.0	0.0	0.0	0.0	1.8	61.0
	10	1.7	3.1	5.6	8.6	30.0	35.8	90.7	39.0
10	20	7.5	7.1	7.7	11.5	16.3	43.8	7.3	0.0
20	30	4.8	8.4	9.2	8.8	29.3	18.9	0.2	0.0
30	40	8.6	6.5	9.0	15.2	29.8	1.5	0.0	0.0
40	50	10.6	8.8	11.1	30.5	2.6	0.0	0.0	0.0
50	60	8.6	12.9	25.3	23.8	0.0	0.0	0.0	0.0
60	70	16.0	28.8	29.0	1.4	0.0	0.0	0.0	0.0
70	80	36.4	23.8	2.7	0.2	0.0	0.0	0.0	0.0
80	90	5.6	0.6	0.4	0.0	0.0	0.0	0.0	0.0
90		0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wardensville									
Zero		0.0	0.0	0.0	0.0	0.0	0.0	5.1	49.4
	10	3.8	4.4	5.3	9.7	16.7	40.2	80.2	50.6
10	20	6.8	8.1	11.4	11.2	19.9	30.3	12.2	0.0
20	30	6.5	7.7	7.7	10.3	16.5	21.1	2.4	0.0
30	40	7.9	8.1	8.3	13.2	23.2	6.3	0.1	0.0
40	50	6.1	7.4	9.7	15.6	17.2	2.0	0.0	0.0
50	60	7.7	8.1	10.8	20.8	5.7	0.1	0.0	0.0
60	70	11.3	10.4	18.9	15.0	0.8	0.0	0.0	0.0
70	80	12.9	19.7	21.7	4.0	0.0	0.0	0.0	0.0
80	90	30.4	24.0	3.0	0.2	0.0	0.0	0.0	0.0
90	100	6.5	24.0	0.2	0.0	0.0	0.0	0.0	0.0
100		0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0

Relative Frequency (%) of Various Levels of Hourly Global Radiation Totals
JUNE

Hourly total, ly ≥	<	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
		Interval, hours from solar noon							
Point Pleasant									
Zero		0.0	0.0	0.0	0.0	0.0	0.0	1.0	46.0
	10	0.8	1.6	3.7	6.4	10.0	27.2	79.3	53.6
10	20	3.7	5.8	7.0	9.2	15.8	40.3	17.1	0.4
20	30	5.1	6.2	8.0	10.8	28.4	27.4	2.6	0.0
30	40	7.0	8.2	6.7	16.2	33.2	4.7	0.0	0.0
40	50	7.2	7.2	14.8	30.0	10.1	0.4	0.0	0.0
50	60	11.8	16.6	30.4	22.2	2.5	0.0	0.0	0.0
60	70	21.0	29.2	24.2	4.4	0.0	0.0	0.0	0.0
70	80	36.4	23.1	4.4	0.8	0.0	0.0	0.0	0.0
80	90	6.6	1.7	0.6	0.0	0.0	0.0	0.0	0.0
90	100	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0
100		0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Wardensville									
Zero		0.2	0.3	0.3	0.3	0.2	0.2	1.3	26.1
	10	1.4	2.6	3.9	6.1	9.2	25.5	78.6	73.5
10	20	5.2	5.6	6.2	7.9	13.1	34.7	17.6	0.4
20	30	7.0	5.7	5.8	7.4	19.0	28.6	2.3	0.0
30	40	5.7	4.2	7.8	11.1	26.3	8.9	0.2	0.0
40	50	6.7	8.4	8.7	19.4	24.3	1.5	0.1	0.0
50	60	9.1	9.3	12.2	25.4	7.3	0.4	0.0	0.0
60	70	10.5	11.9	21.4	17.5	0.6	0.0	0.0	0.0
70	80	15.8	23.9	26.4	4.5	0.0	0.2	0.0	0.0
80	90	30.9	25.8	6.7	0.4	0.0	0.0	0.0	0.0
90	100	7.2	2.3	0.6	0.0	0.0	0.0	0.0	0.0
100		0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Relative Frequency (%) of Various Levels of Hourly Global Radiation Totals

JULY

Hourly total, ly ≥	<	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
Point Pleasant									
Zero		0.0	0.0	0.0	0.2	0.2	0.2	5.3	48.2
	10	2.8	2.0	3.3	4.8	11.3	35.4	78.8	50.5
10	20	5.4	5.9	7.2	11.2	25.0	39.6	13.3	1.3
20	30	5.4	7.2	8.3	17.3	25.9	18.2	2.6	0.0
30	40	6.9	8.7	11.6	18.8	25.4	5.3	0.0	0.0
40	50	10.2	11.5	17.9	27.6	10.2	1.3	0.0	0.0
50	60	13.0	18.0	26.8	16.2	1.8	0.0	0.0	0.0
60	70	20.6	25.2	19.4	3.7	0.2	0.0	0.0	0.0
70	80	28.9	17.6	3.7	0.2	0.0	0.0	0.0	0.0
80	90	5.6	2.8	1.1	0.0	0.0	0.0	0.0	0.0
90	100	1.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0
100		0.2	0.9	0.5	0.0	0.0	0.0	0.0	0.0
Wardensville									
Zero		0.0	0.0	0.0	0.0	0.0	0.1	0.7	41.0
	10	1.4	2.6	3.8	6.2	9.7	34.1	84.7	58.5
10	20	4.9	5.5	6.8	9.1	19.8	37.2	11.9	0.5
20	30	6.6	5.7	7.3	12.2	22.5	21.0	2.7	0.0
30	40	7.2	8.9	8.4	15.4	27.3	6.0	0.0	0.0
40	50	8.7	8.5	12.6	19.6	15.5	1.6	0.0	0.0
50	60	11.8	11.9	16.4	24.2	3.8	0.0	0.0	0.0
60	70	13.5	16.0	23.6	12.1	1.2	0.0	0.0	0.0
70	80	18.3	24.3	17.9	1.1	0.1	0.0	0.0	0.0
80	90	25.2	14.9	3.2	0.1	0.1	0.0	0.0	0.0
90		2.4	1.5	0.0	0.0	0.0	0.0	0.0	0.0

Interval columns: hours from solar noon.

Relative Frequency (%) of Various Levels of Hourly Global Radiation Totals
AUGUST

Hourly total, ly ≥	<	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
Point Pleasant									
Zero		0.0	0.0	0.0	0.0	0.0	0.7	15.1	78.1
	10	1.9	1.6	2.6	4.1	14.8	49.7	77.0	21.6
10	20	4.1	4.7	7.0	15.2	28.1	35.6	6.2	0.3
20	30	5.8	6.0	10.8	16.1	33.4	10.7	1.7	0.0
30	40	6.7	9.6	15.4	26.4	17.3	3.1	0.0	0.0
40	50	9.6	12.6	20.0	24.9	6.2	0.2	0.0	0.0
50	60	19.5	23.2	28.7	11.1	0.2	0.0	0.0	0.0
60	70	28.6	30.8	13.6	1.9	0.0	0.0	0.0	0.0
70	80	22.8	10.8	1.4	0.3	0.0	0.0	0.0	0.0
80	90	1.0	0.5	0.5	0.0	0.0	0.0	0.0	0.0
90		0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Wardensville									
Zero		0.0	0.0	0.1	0.1	0.1	0.6	8.6	72.8
	10	2.0	2.6	3.2	5.7	13.4	47.0	85.3	27.2
10	20	4.2	4.6	6.7	10.2	24.4	39.5	5.8	0.0
20	30	5.9	6.2	8.5	15.0	25.6	9.1	0.3	0.0
30	40	7.1	7.6	11.0	18.1	27.2	3.8	0.0	0.0
40	50	10.7	11.8	13.0	25.1	7.3	0.0	0.0	0.0
50	60	11.4	12.0	20.9	20.0	2.0	0.0	0.0	0.0
60	70	16.1	21.5	26.5	5.5	0.0	0.0	0.0	0.0
70	80	21.5	24.3	8.5	0.3	0.0	0.0	0.0	0.0
80	90	19.8	9.4	1.6	0.0	0.0	0.0	0.0	0.0
90		1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Columns 0-1 through 7-8: Interval, hours from solar noon

Relative Frequency (%) of Various Levels of Hourly Global Radiation Totals
SEPTEMBER

Hourly total, ly ≥	<	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
Point Pleasant									
Zero		0.0	0.0	0.0	0.0	0.0	1.1	50.3	96.9
	10	7.0	6.9	10.6	13.9	32.2	85.4	49.5	3.1
10	20	8.3	11.6	11.2	18.7	38.9	12.6	0.2	0.0
20	30	6.2	9.6	11.4	20.0	24.0	0.7	0.0	0.0
30	40	10.3	8.2	15.2	35.8	4.5	0.2	0.0	0.0
40	50	12.0	17.4	27.6	9.2	0.4	0.0	0.0	0.0
50	60	21.5	27.4	20.4	2.2	0.0	0.0	0.0	0.0
60	70	29.8	17.4	3.4	0.2	0.0	0.0	0.0	0.0
70		4.9	1.5	0.2	0.0	0.0	0.0	0.0	0.0
Wardensville									
Zero		0.0	0.0	0.0	0.0	0.6	5.6	46.7	89.5
	10	3.5	4.7	8.4	13.6	31.2	70.6	50.8	10.5
10	20	9.4	8.5	10.0	16.4	26.8	16.7	2.5	0.0
20	30	5.7	8.0	10.8	16.0	26.4	5.4	0.0	0.0
30	40	7.6	8.4	12.0	21.6	8.6	1.7	0.0	0.0
40	50	8.5	11.9	14.9	20.9	5.2	0.0	0.0	0.0
50	60	10.4	12.8	22.2	7.8	1.2	0.0	0.0	0.0
60	70	17.9	25.6	17.2	3.4	0.0	0.0	0.0	0.0
70	80	30.6	18.4	4.4	0.3	0.0	0.0	0.0	0.0
80	90	6.3	1.7	0.1	0.0	0.0	0.0	0.0	0.0
90		0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0

(Columns 0-1 through 7-8: Interval, hours from solar noon)

Relative Frequency (%) of Various Levels of Hourly Global Radiation Totals
OCTOBER

Hourly total, ly ≥	<	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
Point Pleasant									
Zero		0.0	0.0	0.0	0.0	0.0	12.4	94.0	100.0
	10	4.5	6.9	12.3	20.6	62.0	87.2	6.0	0.0
10	20	9.9	12.0	11.9	26.2	36.0	0.4	0.0	0.0
20	30	11.0	9.9	17.5	39.4	2.0	0.0	0.0	0.0
30	40	13.4	17.2	33.5	13.8	0.0	0.0	0.0	0.0
40	50	18.2	31.2	23.5	0.0	0.0	0.0	0.0	0.0
50	60	35.6	22.2	1.3	0.0	0.0	0.0	0.0	0.0
60		7.4	0.6	0.0	0.0	0.0	0.0	0.0	0.0
Wardensville									
Zero		0.0	0.0	0.0	0.0	1.5	16.5	84.4	99.4
	10	7.4	8.7	11.3	22.0	53.2	78.7	15.6	0.6
10	20	9.4	10.7	14.9	23.6	31.4	4.2	0.0	0.0
20	30	10.2	10.5	12.7	21.8	10.3	0.6	0.0	0.0
30	40	6.4	8.4	15.4	23.2	3.2	0.0	0.0	0.0
40	50	7.7	11.8	25.0	7.2	0.4	0.0	0.0	0.0
50	60	17.2	25.6	17.4	2.1	0.0	0.0	0.0	0.0
60	70	31.1	21.8	3.2	0.1	0.0	0.0	0.0	0.0
70	80	10.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0
80		0.6	0.4	0.1	0.0	0.0	0.0	0.0	0.0

Interval, hours from solar noon

Relative Frequency (%) of Various Levels of Hourly Global Radiation Totals
NOVEMBER

Hourly total, ly ≥	<	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
Point Pleasant									
Zero		0.0	0.0	0.0	0.0	2.7	72.4	97.4	99.0
	10	21.2	24.7	31.8	55.1	95.0	27.6	2.6	1.0
10	20	20.0	20.6	25.8	35.4	2.3	0.0	0.0	0.0
20	30	18.0	19.8	28.8	9.5	0.0	0.0	0.0	0.0
30	40	16.2	24.0	13.4	0.0	0.0	0.0	0.0	0.0
40	50	22.6	10.9	0.2	0.0	0.0	0.0	0.0	0.0
50		2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wardensville									
Zero		0.0	0.0	0.1	0.6	5.6	60.9	97.7	99.8
	10	14.0	16.7	25.0	47.5	84.4	39.0	2.3	0.2
10	20	15.7	17.3	23.6	31.9	8.8	0.1	0.0	0.0
20	30	13.3	15.5	20.9	15.4	1.2	0.0	0.0	0.0
30	40	12.2	17.9	21.2	4.5	0.0	0.0	0.0	0.0
40	50	24.3	25.0	8.3	0.1	0.0	0.0	0.0	0.0
50	60	19.1	7.4	0.7	0.0	0.0	0.0	0.0	0.0
60		1.4	0.2	0.2	0.0	0.0	0.0	0.0	0.0

Interval, hours from solar noon

Relative Frequency (%) of Various Levels of Hourly Global Radiation Totals

DECEMBER

Hourly total, ly ≥	<	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
Point Pleasant									
Zero		0.0	0.0	0.0	0.9	17.8	78.8	93.5	95.7
	10	25.6	32.4	46.0	71.0	81.6	21.2	6.5	4.3
10	20	25.6	25.8	26.6	25.8	0.6	0.0	0.0	0.0
20	30	15.7	18.9	23.0	2.3	0.0	0.0	0.0	0.0
30	40	20.7	20.4	4.4	0.0	0.0	0.0	0.0	0.0
40	50	11.8	2.5	0.0	0.0	0.0	0.0	0.0	0.0
50		0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wardensville									
Zero		0.0	0.0	0.0	0.1	10.3	81.3	100.0	100.0
	10	16.1	19.8	30.6	64.2	89.2	18.7	0.0	0.0
10	20	19.3	22.8	26.6	31.1	0.5	0.0	0.0	0.0
20	30	15.2	16.0	28.2	4.4	0.0	0.0	0.0	0.0
30	40	14.3	26.1	14.2	0.0	0.0	0.0	0.0	0.0
40	50	32.2	15.2	0.4	0.0	0.0	0.0	0.0	0.0
50	60	2.8	0.0	0.0	0.1	0.0	0.0	0.0	0.0
60		0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0

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